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FOREWORD

The *Proceedings* of the American Society for Testing Materials are published annually and include all reports and papers offered to the Society during the current year and accepted by the Administrative Committee on Papers and Publications for the *Proceedings,* together with discussion.

The table of contents and subject and author indexes cover all papers and reports published by the Society during the current year, which in addition to those appearing in the *Proceedings* includes those accepted for publication in the ASTM BULLETIN or in Special Technical Publications.

A list of the Special Technical Publications published by the Society in 1952 is given on the last page of this volume. This supplements the list appearing in the *Proceedings* for 1948 to 1951 covering all special publications published by the Society up to and including 1951.

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SUMMARY OF PROCEEDINGS

OF THE

FIFTY-FIFTH ANNUAL MEETING

(FIFTIETH ANNIVERSARY MEETING)

NEW YORK, N. Y., JUNE 23–27, 1952

This summary of the Fifty-fifth Annual Meeting of the American Society for Testing Materials, held at the Statler and New Yorker Hotels, New York City, June 23–27, 1952, is a record of the transactions of the meeting, including the actions taken on the various recommendations submitted by the technical committees. In all, 36 technical sessions and 3 informal sessions were held.

The registered attendance of the meeting is as follows: Members present or represented, 1375; committee members, 674; guests, 557; total, 2606; ladies, 278.

The Proceedings are set forth session by session. There were 60 reports and 157 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports having been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentatives, and proposed revisions of existing standards, and, as a separate group, the approval of matters that were referred to letter ballot of the Society, comprising the adoption of tentatives as standard and the adoption of revisions of standards. Accordingly, wherever the action is reported "adopted as standard" or "adopted as standard, revisions in" it is understood that this indicates approval of the Annual Meeting for reference to letter ballot of the Society. The various recommendations so recorded are included in the Society letter ballot.[1] The actions designated as "accepted as tentative" or "accepted as tentative, revisions in," are self-evident as indicating acceptance by the Society at the Annual Meeting for publication as tentative.

While all the items on the program are recorded under the particular session in which they are presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all reports together with the page reference where the actions thereon are recorded:

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[1] The letter ballot on recommendations affecting standards, distributed to the Society membership was canvassed on September 30, 1952.

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FIRST SESSION

MONDAY, JUNE 23, 9:30 A.M.

OPENING SESSION

SESSION CHAIRMAN: PRESIDENT T. S. FULLER

Formal Opening of the Fifty-fifth (Fiftieth-Anniversary) Annual Meeting by President T. S. Fuller:

Approval of the Minutes of the 1951 Meeting:

There being no corrections, the Minutes of the 1951 Annual Meeting as set forth in the Summary of Proceedings as published in the 1951 *Proceedings* of the Society were declared approved.

Report of the Board of Directors:

The President called on the Assistant Executive Secretary to present the Report of the Board of Directors. He referred briefly to the report as being one of stewardship on the part of the Board on the direction of the activities of the Society during the year. He also referred to the loss to the Society in the death of its Executive Secretary, C. L. Warwick. In accepting the report of the Board for publication in the *Proceedings*, on motion, it was voted to include in the record of the meeting a minute on the death of Mr. Warwick. This resolution is set forth below:

C. LAURENCE WARWICK

1889–1952

The untimely passing of C. Laurence Warwick on April 23, 1952, has cast a shadow of great sorrow and loss over the entire structure and membership of the Society. He has left behind him a host of friends in the Society and elsewhere, and above all the distinction of having guided, through his leadership and service, the development of the Society from a young and relatively untried organization to the present important position it now holds in the scientific and industrial structure of this country. The standing and many activities of the Society pay tribute to his life.

Mr. Warwick's first associations with the ASTM came during the period from 1909 to 1919 in assisting Dr. Edgar Marburg, first Secretary of the Society. Following the death of Dr. Marburg in 1919 he was elected Secretary-Treasurer, holding this title until 1946 when the title of the executive officer was changed to Executive Secretary. During this entire time he contributed in many ways toward the advancement of the use of standards in the field of materials. One of his early technical services was as secretary of Committee A-1 on Steel, and at various times he was active in other technical committee work. As chairman of the Administrative Committee on Papers and Publications and secretary of the Administrative Committee on Research, notable contributions were rendered by Mr. Warwick in these very important phases of Society activity.

In representing the Society in other organizations, including the American Standards Association, Mr. Warwick played a very influential part in the progress of these organizations and of standardization in general.

During World War II, a large portion of Mr. Warwick's time and energies were directed to the war effort where as head of the Specifications Branch of the Conservation Division, War Production Board, he assisted greatly in the conservation of critical materials.

The membership of the Society will long remember the name of C. Laurence Warwick and the history of ASTM will record his achievements. To each member he will remain as an efficient, helpful and gifted secretary and a loyal friend.

Be it therefore resolved: That this memorial and tribute to his life and services be sent to the family of C. Laurence Warwick and that it be recorded in the *Proceedings* of the American Society for Testing Materials.

The President then relinquished the chair to Mr. E. L. Robinson who served as chairman of the Symposium Session which followed immediately.

SYMPOSIUM ON EFFECTS OF NOTCHES AND METALLURGICAL CHANGES ON STRENGTH AND DUCTILITY OF METALS AT ELEVATED TEMPERATURES[2]

SESSION CHAIRMAN: E. L. ROBINSON

SECRETARY: G. V. SMITH

A Survey of Embrittlement and Notch Sensitivity of Heat-Resisting Steels—George Sachs and W. F. Brown, Jr., presented by Mr. Sachs.

Effect of a Notch and of Hardness on the Rupture Strength of "Discaloy"—F. C. Hull, E. K. Hann, and H. Scott, presented by Mr. Hull.

The Influence of Sharp Notches on the Stress-Rupture Characteristics of Several Heat-Resisting Alloys—W. F. Brown, Jr., M. H. Jones, and D. P. Newman, presented by Mr. Brown.

The Effect of Grain Size Upon the Fatigue Properties at 80, 1200 and 1600 F of "Precision-Cast" Alloy X-40,—P. R. Toolin, presented from manuscript by the author.

(*Symposium Continued in Third and Sixth Sessions*)

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[2] Issued as a separate publication entitled Symposium on Strength and Ductility of Metals at Elevated Temperatures with Particular Reference to Effects of Notches and Metallurgical Changes, *STP No. 128.*

SECOND SESSION—SYMPOSIUM ON TIN[3]

MONDAY, JUNE 23, 9:45 A.M.

CO-CHAIRMEN: G. W. GONSER AND SIDNEY ROLLE

Introductory Remarks—Bruce W. Gonser.

Tin Production and Resources—F. Stuart Miller, presented from manuscript by the author.

Tin Coatings—Frederick A. Lowenheim, presented from manuscript by the author.

Trends in the Use of Tin in the Container Industry—Richard R. Hartwell, presented from manuscript by the author.

Tin in Automobile Body Construction—Homer Pratt, presented from manuscript by the author.

(*Symposium Continued in Fourth Session*)

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[3] Issued as a separate publication, *STP No. 141.*

THIRD SESSION—SYMPOSIUM ON EFFECTS OF NOTCHES AND METALLURGICAL CHANGES ON STRENGTH AND DUCTILITY OF METALS AT ELEVATED TEMPERATURES[2]

(*Continued from First Session*)

MONDAY, JUNE 23, 2:00 P.M.

SESSION CHAIRMAN: H. C. CROSS

SECRETARY: G. V. SMITH

Investigations into the Effect of Notches on the Results of Long-Time Rupture Tests at the Elevated Temperatures—W. Siegfried, presented from manuscript by D. R. Herold.

Theory of Time-Dependent Rupture and Interpretation of Some Stress-Rupture Data—D. N. Frey, presented by the author.

Effect of Notch Geometry on Rupture Strength at Elevated Temperatures—E. A. Davis and M. J. Manjoine, presented by Mr. Manjoine.

(*Symposium Continued in Sixth Session*)

FOURTH SESSION—SYMPOSIUM ON TIN[3]

(*Continued from Second Session*)

MONDAY, JUNE 23, 2:00 P.M.

SESSION CO-CHAIRMEN: W. C. BOWDEN, JR. AND ROBERT H. TAYLOR

The Effect of Impurities on the Performance of Tin—Frederick J. Dunkerley, presented from manuscript by the author.*

The Determination of Small Amounts of Impurities in Tin—Marie Farnsworth and Joseph Pekola, presented from manuscript by Miss Farnsworth.

Panel Discussion—Analysis of Tin (In cooperation with Committees E-2 and E-3).

Summary—Sidney Rolle.

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* This paper has since been withdrawn and is being replaced by a similar paper written by C. L. Mantell.

FIFTH SESSION—GILLETT MEMORIAL LECTURE

MONDAY, JUNE 23, 4:00 P.M.

SESSION CHAIRMAN: PRESIDENT T. S. FULLER

First Gillett Memorial Lecture:

President Fuller called upon Past-President R. L. Templin who remarked upon the establishment of the H. W. Gillett Memorial Lecture. This lecture is sponsored jointly by the ASTM and the Battelle Memorial Institute to perpetuate the memory of Horace W. Gillett, one of America's leading technologists, the first Director of Battelle Institute, and for many years a very active worker in the Society, through the presentation of a lecture on a subject pertaining to the development, testing, evaluation, and application of metals.

Mr. Clyde E. Williams, the present Director of Battelle Institute, then introduced Mr. Norman L. Mochel as the first Gillett Memorial Lecturer, who spoke on "Man, Metals, and Power." Mr. Mochel paid tribute to Dr. Gillett and made mention of his various interests both technical and personal. Since the Gillett Lecture deals with the development, testing, evaluation or application of metals, in all of which Dr. Gillett was active, Mr. Mochel outlined the application of metals in all fields of manufactured power, pointing out that our very existence and survival are dependent upon power development.

President Fuller expressed appreciation of Mr. Mochel for his splendid lecture and presented to him on behalf of the Society the H. W. Gillett Memorial Lecture Certificate.

SYMPOSIUM ON INSULATING OIL

MONDAY, JUNE 23, 8:00 P.M.

At the Symposium on Insulating Oil consideration was given to reclamation of used oils after various stages of deterioration of service. Special consideration was given to methods of reconditioning, re-refining, and inhibiting used oils which might economically extend the life of oils in electric utility service. A paper on "Reclaiming and Inhibiting of Oil" was presented by F. C. Doble. The Symposium Session was concluded by a general discussion.*

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* It is planned to publish the paper and discussion as a Special Technical Publication.

SIXTH SESSION—SYMPOSIUM ON EFFECTS OF NOTCHES AND METALLURGICAL CHANGES ON STRENGTH AND DUCTILITY OF METALS AT ELEVATED TEMPERATURES[2]

(*Continued from First and Third Sessions*)

MONDAY, JUNE 23, 8:00 P.M.

SESSION CHAIRMAN: H. C. CROSS

SECRETARY: G. V SMITH

An Experimental Study of the Strength and Ductility of Steel at Elevated Temperatures—J. Glen, presented from manuscript by the author.

Effect of Sigma on Strength and Ductility of 25 Cr, 20 Ni Steel—G. V. Smith and E. J. Dulis, presented by Mr. Dulis.

Recovery and Creep in an Alloy Steel—H. A.

Lequear and J. D. Lubahn, presented by Mr. Lubahn.

The Structure and Properties of Stainless Steels After Exposure at Elevated Temperatures—A. B. Wilder and E. F. Ketterer, presented from manuscript by Mr. Wilder.

Summary—G. V. Smith.

Exploratory Investigation of High-Temperature Sheet Materials—D. Preston, presented by the author.

SEVENTH SESSION—SYMPOSIUM ON CONTINUOUS ANALYSIS OF INDUSTRIAL WATER AND INDUSTRIAL WASTE WATER

TUESDAY, JUNE 24, 9:00 A.M.

SESSION CHAIRMAN: B. W. DICKERSON

Committee D-19 on Industrial Water:

Report presented by Max Hecht, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Substitute Ocean Water (D 1141 - 50 T)

Method for Identification of Crytalline Compounds in Water-Formed Deposits by X-Ray Diffraction (D 934 - 50 T)

Method for Nitrate Ion in Industrial Water D 992 - 48 T)

Adopted as Standard, Revisions in:

Method for Calcium Ion and Magnesium Ion in Industrial Water (D 511 - 42)

Method of Corrosivity Test (USBM Embrittlement Detector Method (D 807 - 49)

Symposium on Industrial Water:[4]

Introduction—B. W. Dickerson.

Automatic Sampling of Industrial Water and Industrial Waste Water—M. F. Madarasz, presented from manuscript by the author.

Some Practical Aspects of the Measurement of pH, Electrical Conductivity and Oxidation-Reduction Potential of Industrial Water—Robert Rosenthal, presented from manuscript by the author.

(*Symposium Continued in Eleventh Session*)

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[4] Issued as a separate publication, *STP No. 130.*

EIGHTH SESSION—SYMPOSIUM ON FATIGUE, WITH EMPHASIS ON STATISTICAL APPROACH[5]

TUESDAY, JUNE 24, 9:00 A.M.

SESSION CHAIRMAN: W. J. YOUDEN

SECRETARY: W. T. LANKFORD

Introduction—W. J. Youden

The Statistical Nature of the Fatigue Properties of SAE 4340 Steel Forgings—J. T. Ransom and R. F. Mehl, presented by Mr. Ransom.

The Statistical Behavior of Fatigue Properties and the Influence of Metallurgical Factors—E. Epremian and R. F. Mehl, presented from manuscript by G. T. Horne.

An Analysis of Scatter in Fatigue Testing—Frank A. McClintock, presented from manuscript by the author.*

A Statistical Interpretation of the Effect of Understressing on Fatigue Strength—E. Epremian and R. F. Mehl, presented by G. T. Horne.

Fatigue Properties of Large Specimens with Related Size and Statistical Effects—O. J. Horger and H. R. Neifert, presented from manuscript by Mr. Neifert.

(*Other Papers on Fatigue Presented in Twelfth and Nineteenth Sessions*)

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[5] Issued as a separate publication, *STP No. 137.*

* Not published as part of *STP No. 137.*

NINTH SESSION—SYMPOSIUM ON CONDITIONING AND WEATHERING[6]

TUESDAY, JUNE 24, 9:00 A.M.

SESSION CHAIRMAN: A. C. WEBBER

Introduction—A. C. Webber.

Fundamentals of Atmospheric Elements—Benarthur C. Haynes, presented by Mr. A. C. Kussman.

Air Conditioning in the Manufacture and Testing of Textiles—R. H. Brown

Conditioning and Weathering of Paper—William R. Willets, presented by the author.

Conditioning and Weathering of Adhesives and Plastics—Frank Reinhart, presented from manuscript by the author.

Weathering of Some Organic Coatings—E. J. Dunn, Jr., presented from manuscript by the author.

Weathering Tests on Metallic Coatings—William Blum, presented from manuscript by the author.

Laboratory Air Conditioning—A. E. Stacey, Jr., presented by the author.

Development of a Moisture Resistance Test—C. P. Lascaro, presented from manuscript by the author.

Outdoor Exposure Testing on Racks and Test Fences—K. G. Compton, presented from manuscript by the author.

Accelerated Weathering Devices—Roscoe H. Sawyer, presented from manuscript by the author.

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[6] Issued as a separate publication, *STP No. 133.*

TENTH SESSION—LUNCHEON SESSION—PRESIDENT'S ADDRESS, RECOGNITION OF AMERICAN AND FOREIGN DELEGATES, AWARDS OF MERIT, RECOGNITION OF 40- AND 50-YEAR MEMBERS, INTRODUCTION OF NEW OFFICERS

TUESDAY, JUNE 24, 12:15 P.M.

CHAIRMAN: PAST-PRESIDENT L. J. MARKWARDT

The Tuesday Luncheon Session was one of the highlight features of the Fiftieth-Anniversary Annual Meeting. There were over 400 in attendance including a number of representatives of organizations both here and abroad.

Presentation of Awards of Merit:

The Chairman of the 1952 Award of Merit Committee, L. J. Trostel, read brief citations and presented the following men to President Fuller, who conferred on them, on behalf of the Board of Directors, the certificate of the Award of Merit:

Wheeler P. Davey
George H. Harnden
Jay C. Harris
Jerome J. Kanter
H. S. Mattimore
Douglas E. Parsons
Hugh M. Robinson
John D. Sullivan
Ray Thomas
Fred D. Tuemmler

Report of Tellers; Introduction of New Officers:

The Report of Tellers on the election of officers was presented by Sherman R. Doner and E. R. Thomas on behalf of the tellers. The following new officers were then introduced:

For President, to serve for one year:

H. L. Maxwell (936 votes)

For Vice-President, to serve for two years:

N. L. Mochel (936 votes)

For Directors, to serve for three years:

G. R. Gohn (936 votes)
W. H. Lutz (936 votes)
H. K. Nason (936 votes)
A. O. Schaefer (936 votes)
M. A. Swayze (936 votes)

Presidential Address:

The annual President's Address was presented by T. S. Fuller, his subject being "Some Gratifying Results." This address appears on p. 37.

Tribute to the late Executive Secretary C. L. Warwick:

In recognition and tribute to the late Executive Secretary, C. L. Warwick, Past-President L. J. Markwardt spoke briefly, following which he asked that those present rise for a moment in silent tribute. Mr. Markwardt's remarks are recorded in the July ASTM BULLETIN.

Recognition of Delegates:

Delegates from government departments, American and foreign societies, and trade groups were recognized. Response for the American and Canadian Delegates was made by Dr. R. E. Zimmerman, Vice-President of United States Steel Co., under the title "Technical Minds Meet;" these remarks are published in the July ASTM BULLETIN. The response for Delegates from across the seas was made by Dr. Albert Caquot, President, International Standards Organization (translation by Henry St. Leger, Secretary-General, International Standards Organization).

Recognition of 40- and 50-year Members:

The Chairman read the names of those members both individual and companies who have been affiliated with the Society for 40 and 50 years. A list of these members appears in the preprinted Report of the Board of Directors and the July ASTM BULLETIN.

ELEVENTH SESSION—SYMPOSIUM ON CONTINUOUS ANALYSIS OF INDUSTRIAL WATER AND INDUSTRIAL WASTE WATER[4]

(*Continued from Seventh Session*)

TUESDAY, JUNE 24, 2:30 P.M.

SESSION CHAIRMAN: R. C. ADAMS
SECRETARY: B. W. DICKERSON

Continuous Recording of Chlorine Residuals and Determination of Chlorine Demand—A. E. Griffin, presented from manuscript by the author.

Measurement of Color, Turbidity, Hardness, and Silica in Industrial Waters—F. C. Staats, presented by the author.

Continuous Measurement of Dissolved Gases in Water—J. K. Rummel, presented by the author.

Summary—B. W. Dickerson.

TWELFTH SESSION—FATIGUE

TUESDAY, JUNE 24, 2:30 P.M.

SESSION CHAIRMAN: G. R. GOHN
SECRETARY: W. T. LANKFORD

Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum—T. J. Dolan and H. F. Brown, presented by Mr. Dolan.

An Investigation of the Coaxing Effect in Fatigue of Metals—G. M. Sinclair, presented by the author.

The Anisotrophy of the Fatigue Properties of SAE 4340 Steel Forgings—J. T. Ransom and R. F. Mehl, presented by Mr. Ransom.

Fatigue Strength of Refractaloy-26 as Affected by Temperature, Hardness, and Grain

Size—F. C. Hull and P. R. Toolin, presented from manuscript by Mr. Toolin.

A Study of Fatigue of Steels Due in the Finite Region of the *S-N* Curves—Walter G. Finch, presented from manuscript by the author.

An Inquiry Into the Reproducibility of Impact Test Results—Humphrey L. Fry, presented by the author.[7]

(*Papers on Fatigue Continued in Nineteenth Session*)

THIRTEENTH SESSION—SYMPOSIUM ON APPLICATION OF THE ELECTRON MICROSCOPE TO METALLURGY

TUESDAY, JUNE 24, 2:30 P.M.

SESSION CHAIRMAN: L. L. WYMAN

SECRETARY: D. M. TEAGUE

Committee E-4 on Metallography:

Report presented by L. L. Wyman, Chairman, and the following action taken:

Adopted as Standard:

Methods for Estimating the Average Ferrite Grain Size of Low-Carbon Steels (E 89 - 50 T)

Papers:

Electron Microstructure of Bainite in Steel. Second Progress Report by Subcommittee XI of ASTM Committee E-4, Printed as an appendix to the Report of Committee E-4. D. M. Teague, presented by the author.

Pre-Shadowed Replicas for Electron Metallography—William L. Grube, presented from manuscript by the author.

Electron-Diffraction Study of Iron Carbides in Bainite and Tempered Martensite—A. E. Austin and C. M. Schwartz, presented by Mr. Schwartz.

Quantitative Metallography with the Electron Microscope. Part II. Lineal Analysis—Alfred L. Ellis, presented from manuscript by the author.*

An Electron Microscope Study of the Development of Fatigue Failure—W. J. Craig, presented by the author.

FOURTEENTH SESSION—COMMEMORATIVE PAPERS ON FIFTIETH ANNIVERSARY OF COMMITTEE D-1 ON PAINT[8]

TUESDAY, JUNE 24, 2:30 P.M.

SESSION CHAIRMAN: W. T. PEARCE

SECRETARY: W. H. LUTZ

Introduction—E. W. Boughton, C. H. Rose, and W. T. Pearce.

Accelerated Tests for Protective Coatings—R. H. Sawyer, presented from manuscript by the author.

Varnish—J. C. Weaver, presented from manuscript by the author.

Exterior Exposure Testing on Wood—W. G. Vannoy, presented from manuscript by the author.

Physical Properties of Material—M. R. Euverard, presented from manuscript by the author.

Cellulosic Coatings, Related Materials—F. H. Lang, presented from manuscript by the author.

Painting of Metals—A. J. Eickhoff, presented from manuscript by the author.

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[7] Published in ASTM BULLETIN No. 187, January 953 p. 61 (TP15).

* Not published.

[8] Issued as a separate publication, *STP No. 147*.

FIFTEENTH SESSION—REPORT SESSION

TUESDAY, JUNE 24, 5:00 P.M.

SESSION CHAIRMAN: L. B. JONES

Committee A-1 on Steel:

Report presented by N. L. Mochel, chairman, and the following actions taken:

Accepted as Tentative:

Methods and Definitions for the Mechanical Testing of Structural Steel

Spec. for Heavy-Walled Carbon and Alloy Steel Castings for Steam Turbines

Spec. for 5 per cent Chromium, 0.5 per cent Molybdenum Steel Plates for Boilers and Other Pressure Vessels

Spec. for Alloy Steel Bars for Nitriding

Spec. for Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steel Pipe for High-Temperature Service

Adopted as Standard:

Spec. for Heat-Treated Steel Helical Springs (A 125 - 50 T)

Accepted as Tentative, Revisions in:

Spec. for General Requirements for Delivery by Rolled Steel Plates, Shapes, and Bars for Structural Uses and Sheet Piling (A 6 - 52 T)

Spec. for Steel for Bridges and Buildings (A 7 - 50 T)

Spec. for Structural Nickel Steel (A 8 - 52 T)

Spec. for Mild-To Medium-Strength Carbon-Steel Castings for General Application (A 27 - 50 T)

Spec. for Structural Silicon Steel (A 94 - 50 T)

Spec. for Hot-Rolled Carbon-Steel Bars (A 107 - 52 T)

Spec. for Cold-Finished Carbon-Steel Bars and Shafting (A 108 - 50 T)

Spec. for Structural Steel for Locomotives and Cars (A 113 - 50 T)

Spec. for Structural Steel for Ships (A 131 - 50a T)

Spec. for Structural Rivet Steel (A 141 - 50 T)

Spec. for Electric-Fusion-Welded Steel Pipe for High Temperature and High Pressure Work (A 155 - 52 T)

Spec. for High-Strength Structural Rivet Steel (A 195 - 50 T)

Spec. for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 51 T)

Spec. for Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 - 51 T)

Spec. for Low-Alloy Structural Steel (A 242 - 50 T)

Spec. for Carbon Steel Forgings for General Industrial Use (A 235 - 49 T)

Spec. for Carbon Steel Forgings for Locomotives and Cars (A 236 - 49 T)

Spec. for Alloy Steel Forgings for General Industrial Use (A 237 - 49 T)

Spec. for Heavy Gage Structural Quality Flat Hot-Rolled Carbon-Steel Sheets (A 245 - 48 T)

Spec. for Light Gage Structural Quality Flat Rolled Carbon-Steel Sheets (A 246 - 48 T)

Spec. for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger, and Condenser Tubes (A 249 - 51 T)

Spec. for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness (A 283 - 50 T)

Spec. for Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates for Machine Parts and General Construction (A 284 - 51 T)

Spec. for Carbon Steel Forgings for Rings for Main Reduction Gears (A 290 - 49 T)

Spec. for Carbon and Alloy Steel Forgings for Pinions for Main Reduction Gears (A 291 - 49 T)

Spec. for Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 52 T)

Spec. for Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts (A 293 - 50 T)

Spec. for Hot-Rolled Carbon-Steel Strip of Structural Quality (A 303 - 48 T)

Spec. for Carbon-Steel Bars Subject to Mechanical property Requirements (A 306 - 52 T), with the addition of Vanadium *c* at the end of Table VI, and the permissible variations reading 0.03, 0.03, 0.03, 0.04, 0.04.

Spec. for Steel Machine Bolts and Nuts and Tap Bolts (A 307 - 50 T)

Spec. for Stress-Relief-Annealed Cold-Drawn Carbon-Steel Bars (A 311 - 49 T)

Spec. for Steel Sheet Piling (A 328 - 50 T)

Spec. for Seamless Ferritic Alloy Steel Pipe for High Temperature Service (A 335 - 52 T)

Editorial Changes Accepted in:

Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 51 T)

Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 51 T)

Spec. for Seamless Alloy-Steel Boiler, Superheater and Heat Exchanger Tubes (A 213 - 51 T)

Spec. for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 – 51 T)
Spec. for Hot-Rolled Carbon-Steel Bars (A 107 – 52 T)
Spec. for Cold-Finished Carbon-Steel Bars and Shafting (A 108 – 50 T)
Spec. for Heat-Treated Alloy Steel Bars (A 286 – 52 T)
Spec. for Alloy-Steel Bars to End-Quench Hardenability Requirements (A 304 – 52 T)
Spec. for Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 – 52 T)
Spec. for Stress-Relief-Annealed Cold-Drawn Carbon-Steel Bars (A 311 – 49 T)
Spec. for Heat-Treated Carbon-Steel Bars (A 321 – 52 T)
Spec. for Hot-Rolled Alloy-Steel Bars (A 322 – 52 T)
Spec. for Cold-Finished Alloy-Steel Bars (A 331 – 52 T)

Revision of Standard, Immediate Adoption:

Spec. for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 47)
Spec. for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 47)

Committee A-2 on Wrought Iron:

Report presented by A. D. Morris, chairman, and accepted as a report of progress.

Committee A-6 on Magnetic Properties:

Report Presented by R. L. Sanford, chairman, and the following action taken:

Adoption as Standard, Revision in:

Test for Electrical and Mechanical Properties of Magnetic Materials (A 344 – 49): in Section 26, Change 5000 Kg (11,000 lb) to 550 Kg (12,000 lb).

Committee A-7 on Malleable-Iron Castings:

Report presented by W. A. Kennedy, chairman, and the following action taken:

Adoption as Standard, Revision in:

Spec. for Malleable-Iron Castings (A 47 – 48), with the addition of the word "some" between the words "of" and "railroad" in the second and third lines of Section 7(*a*).

Committee A-9 on Ferro-Alloys:

Report presented by W. C. Bowden, Jr., chairman, and the following action taken:

Adopted as Standard:

Spec. for Molybdenum Salts and Compounds (A 146 – 50 T)
Spec. for Ferroboron (A 323 – 50 T)
Spec. for Ferrotitanium (A 324 – 50 T)

Committee D-7 on Wood:

Report presented by L. J. Markwardt, chairman, and the following actions taken:

Adopted as Standard:

Nomenclature of Domestic Hardwoods and Softwoods (D 1165 – 51 T)
Definitions Relating to Veneer and Plywood (D 1038 – 49 T), as revised

Accepted as Tentative, Revision in:

Methods for Evaluating the Properties of Fiber Building Boards (D 1037 – 49 T)
Spec. for Round Timber Piles (D 25 – 37)

Adopted as Standard, Revision in:

Methods of Testing Small Clear Specimens of Timber (D 143 – 50)
Methods of Testing Plywood, Veneer, and Other Wood and Wood-Base Materials (D 805 – 47)

Committee E-2 on Emission Spectroscopy:

Report presented by title only.

Committee E-3 on Chemical Analysis of Metals:

Report presented by J. W. Stillman, chairman, and the following actions taken:

Adopted as Standard:

Methods for Chemical Analysis of Steel (E 30 – 50 T)

Editorial Changes Accepted in:

Methods of Sampling Ferro-Alloys (E 32 – 42)

Committee E-7 on Non-Destructive Testing:

Report presented by J. H. Bly, chairman, and the following action taken:

Adopted as Standard:

Industrial Radiographic Standards for Steel Castings (E 71 – 47 T)

Committee E-11 on Quality Control of Materials:

Report presented by H. F. Dodge, chairman, and accepted as a report of progress.

Joint Committee on Effect of Temperature on the Properties of Metals:

Report presented by Ernest L. Robinson, chairman.

SIXTEENTH SESSION—SYMPOSIUM ON LIGHT MICROSCOPY

WEDNESDAY, JUNE 25, 9:30 A.M.

SESSION CHAIRMAN: R. P. LOVELAND
SECRETARY: F. G. FOSTER

Committee E-1 on Methods of Testing:

Report presented by J. R. Townsend, chairman, and the following actions taken:

Adopted as Standard:

Hardness Conversion Table for Nickel and High-Nickel Alloys

Accepted as Tentative:

Method for Diamond Pyramid Hardness of Metallic Materials

Accepted as Tentative, Revision in:

Methods of Tension Testing of Metallic Materials (E 8 - 51 T)

Adopted as Standard, Revision in:

Spec. for ASTM Thermometers (E 1 - 51), except that under the Aniline Point Thermometer 34 F, change the distance from bottom of bulb to graduation line at 77 F from "101 to 115 mm" to "112 to 114 mm;" also change the distance from top of thermometer to graduation line at 221 F from "25 to 45 mm" to "32 to 51 mm." The Oil in Wax Thermometer in the report as preprinted replaces the present Thermometer 55 F which will be discontinued. The proposed revision of the Saybolt Viscosity Thermometers 17 C to 22 C and 17 F to 22 F to omit the requirement for marking of special graduations in contrasting color was withdrawn from the report as this revision was not approved by Committee D-2 and will be given further study.

Symposium on Light Microscopy:[9]

Introduction—R. P. Loveland.

The Methods of Microscopy—C. W. Mason, presented from manuscript by the author.

Apparatus for Microscopy—H. W. Zieler, presented from manuscript by the author.

Some Applications of Light Microscopy in the Study of Textile Materials—Verne W. Tripp, presented from manuscript by the author.

Polarized Light Microscopy of Crystals—W. C. McCrone, presented from manuscript by the author.

Applications of Light Microscopy in Concrete Research—Katherine Mather, presented from the manuscript by the author.

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[9] Issued as a separate publication, *STP No. 143.*

(*Symposium Continued in Twentieth Session*)

SEVENTEENTH SESSION—SYMPOSIUM ON DETERMINATION OF ELASTIC CONSTANTS[10]

WEDNESDAY, JUNE 25, 9:30 A.M.

SESSION CHAIRMAN: PAST PRESIDENT R. L. TEMPLIN
SECRETARY: WALTER RAMBERG

Report of ASTM Task Group for Determination of Elastic Constants—Walter Ramberg, presented by the author.

Influence of Temperature on the Elastic Constants of Some Commercial Steels—F. Garofalo, P. R. Malenock, and G. V. Smith, presented by Mr. F. Garofalo.

Methods for Determining the Elastic Constants of Non-Metallic Materials—E. W. Kuenzi, presented by the author.

Dynamic Methods for Determining Elastic Constants and Their Temperature Variation in Metals—M. E. Fine, presented from manuscript by the author.

An Evaluation of Several Static and Dynamic Methods for Determining Elastic Moduli—J. T. Richards, presented from manuscript by the author.

Summary—Walter Ramberg.

Rheotropic Embrittlement—E. J. Ripling, presented by the author.[11]

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[10] Issued as a separate publication, *STP No. 129.*

[11] Published in ASTM BULLETIN No. 186, December 1952, p. 37 (TP179).

EIGHTEENTH SESSION—SYMPOSIUM ON FRETTING CORROSION[12]

WEDNESDAY, JUNE 25, 9:30 A.M.

SESSION CHAIRMAN: T. E. DEVILLIERS

The Present Status of Fretting Wear—W. E. Campbell, presented from manuscript by the author.

NACA Research on Fretting. (Film)—Douglas Godfrey, presented from manuscript by the author.

Fretting Corrosion Tendencies of Several Combinations of Materials—J. R. McDowell, presented from manuscript by the author.

(*Symposium Continued in Twenty-First Session*)

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[12] Issued as a separate publication, *STP No. 144.*

NINETEENTH SESSION—FATIGUE

(*Continued from Eighth and Twelfth Sessions*)

WEDNESDAY, JUNE 25, 9:30 A.M.

SESSION CHAIRMAN: T. J DOLAN

SECRETARY: W. T. LANKFORD

Committee E-9 on Fatigue:

Report presented by R. E. Peterson, chairman, and accepted as a report of progress.

Papers:

Plastic-Flow and Work-Hardening Phenomena During Fixed-Deflection Fatigue Tests of Magnesium Alloys—E. H. Schuette, presented from manuscript by the author.

Fatigue of 76S-T61 Aluminum Alloy Under Combined Bending and Torsion—W. N. Findley, presented by the author.

Fatigue Machines for Low Temperatures and for Miniature Specimens—W. N. Findley, P. G. Jones, W. I. Mitchell, and R. L. Sutherland, presented from manuscript by Mr. Findley.[13]

Effect of Tensile and Compressive Fatigue Stress on Creep, Rupture, and Ductility Properties of Temperature Resistant Materials—B. J. Lazan and E. Westberg, presented from manuscript by Mr. Lazan.

Dynamic Testing of Materials and Structures with a New Resonance Vibration Exciter and Controller—B. J. Lazan, A. Gannett, P. Kirmser, J. Klumpp, and J. Brown, presented from manuscript by Mr. Lazan.

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[13] Published in ASTM BULLETIN No. 184, September 1952, p. 53 (TP137).

TWENTIETH SESSION—SYMPOSIUM ON LIGHT MICROSCOPY[9]

(*Symposium Continued from Sixteenth Session*)

WEDNESDAY, JUNE 25, 2:00 P.M.

SESSION CHAIRMAN: F. G. FOSTER

SECRETARY: R. P. LOVELAND

The Microscopic Examination of Metallic Specimens—J. R. Vilella, presented from manuscript by the author.

Resinography, the Microscopy of Resins and Plastics—T. G. Rochow, presented from manuscript by the author.

Particle Size—R. P. Loveland, presented from manuscript by the author.

Summary—G. P. Royer.

TWENTY-FIRST SESSION—SYMPOSIUM ON FRETTING CORROSION[12]

(Continued from Eighteenth Session)

WEDNESDAY, JUNE 25, 2:00 P.M.

SESSION CHAIRMAN: VICE-PRESIDENT L. C. BEARD, JR.

SECRETARY: T. E. DEVILLIERS

Fretting Corrosion in Fitted Members—O. J. Horger, presented from manuscript by H. R. Neifert.

Effect of Lubricants in Minimizing Fretting Corrosion—E. W. Herbek and R. F. Strohecker, presented from manuscript by Mr. Herbek.

Test Equipment for Evaluating Fretting Corrosion—H. H. Uhlig, W. D. Tierney and A. McClellan, presented from manuscript by Mr. Uhlig.

SYMPOSIUM ON NON-DESTRUCTIVE TESTING[14]

THURSDAY, JUNE 26, 9:30 A.M. AND 2:00 P.M.

Field Radiography in Denmark; New Methods and Equipment—Hans Vinter, Danish Central Institute of Welding, Klampenberg, Denmark.

Development of Standard Comparison Radiographs of Steel Welds—A. Gobus, Sam Tour & Co., N. Y. C. and N. A. Kahn, N. Y. Naval Shipyard.

British Practice in Gamma-radiography*—M. Falk, M. Falk & Co., Ltd., London, England.

Radiography and Fluoroscopy with Multicurie Iridium 192 Sources—C. Garrett & G. Rice, National Research Council, Ottawa, Canada; and A. H. Morrison, Arthur D. Little, Inc., Cambridge, Mass.

Weld Radiography a Tentative Method for the Quantitative Evaluation of Defects—O. Masi, Instituto Scientifico Tecnico E. Brade., Milan, Italy.

Critical Study of Techniques for the Testing of Materials by Ultrasonic Methods.—P. Bastien, Schneider Creuzot, Paris, France.

Comparison of Non-destructive Tests on a Damaged Stern-Post—A. de Sterke and H. den Hartog, Roentgen Technische Dienst, Overshie, Holland.

Progress in the Field of Non-destructive Testing Through the Use of Ultrasonics—W. C. Hitt, Douglas Aircraft Co., Santa Monica, Calif.

The Practical Application of Ultrasonic Nondestructive Testing—W. E. Felix, Sulzer Bros., Winterthur, Switzerland.

New Magnetic Non-destructive Tests—F. Forster, Institut Dr. Forster, Reutlingen, Germany.

TWENTY-SECOND SESSION—NON-FERROUS METALS

WEDNESDAY, JUNE 25, 2:00 P.M.

SESSION CHAIRMAN: G. H. HARNDEN

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by H. C. Ashley, vice-chairman, in the absence of the chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Rectangular Copper Wire for General Purpose

Spec. for Copper-Base Alloy Centrifugal Castings

Accepted as Tentative, Revisions in:

Spec. for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 – 51 T)

Spec. of Copper-Nickel, Zinc and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 – 51 T)

Spec. for Copper, Rod, Bar, and Shapes (B 133 – 51 T)

Spec. for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar (B 248 – 51 T)

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[14] Issued as a separate publication, *STP No. 145.*

* This paper has been withdrawn since its presentation.

Spec. for General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes (B 249 - 51 T)
Spec. for General Requirements for Wrought Copper-Alloy Wire (B 250 - 51 T)
Spec. for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 - 51 T)

Adopted as Standard:

Spec. for Brass Plate, Sheet, Strip, and Rolled Bar (B 36 - 51 T)
Spec. for Seamless Copper Tube (B 75 - 51 T)
Spec. for Gilding Metal Strip (B 130 - 51 T)
Spec. for Phosphor Bronze Wire (B 159 - 51 T)
Spec. for Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar (B 169 - 51 T)
Spec. for Seamless Copper Bus Pipe and Tube (B 188 - 51 T)
Classification of Coppers (B 224 - 48 T)

Adopted as Standard, Revisions in:

Spec. for Naval Brass Rod, Bar and Shapes (B 21 - 51 T)
Spec. for Leaded Brass Plate, Sheet, Strip, and Rolled Bar (B 121 - 51 T)
Spec. for Seamless Brass Tube (B 135 - 51 T)
Spec. for Phosphor Bronze Rod, Bar, and Shapes (B 139 - 51 T)
Spec. for Aluminum Bronze Rod, Bar, and Shapes (B 150 - 51 T)
Spec. for Copper-Nickel-Zinc Alloy Rod and Bar (B 151 - 51 T)
Spec. for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 - 51 T)
Spec. for Beryllium-Copper Alloy Plate, Sheet, Strip, and Rolled Bar (B 194 - 51 T)
Spec. for Beryllium-Copper Alloy Rod and Bar (B 196 - 51 T)
Spec. for Beryllium-Copper Alloy Wire (B 197 - 51 T)
Spec. for Copper-Nickel-Zinc Alloy wire (B 206 - 51 T)
Spec. for Copper Rods for Locomotive Staybolts (B 12 - 51)
Spec. for Free-Cutting Brass Rod, Bar, and Shapes for Use in Screw Machines (B 16 - 51)
Spec. for Bronze Castings for Bridges and Turntables (B 22 - 51)
Spec. for Seamless Copper Pipe, Standard Sizes (B 42 - 51)
Spec. for Seamless Red Brass Pipe, Standard Sizes (B 43 - 51)
Spec. for Steam or Valve Bronze Castings (B 61 - 51)
Spec. for Composition Brass or Ounce Metal Castings (B 62 - 51)
Spec. for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 - 49)
Spec. for Car and Tender Journal Bearings, Lined (B 67 - 49)
Spec. for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 - 51)
Spec. for Rolled Copper-Alloy Bearing and Expansion Plates and Sheet for Bridge and Other Structural Uses (B 100 - 49)
Spec. for Copper and Copper-Alloy Seamless Condesner Tubes and Ferrule Stock (B 111 - 51)
Spec. for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 - 51)
Spec. for Leaded High-Strength Yellow Brass (Manganese Bronze Sand Castings) (B 132 - 49)
Spec. for Brass Wire (B 134 - 51)
Spec. for Manganese Bronze Rod, Bar, and Shapes (B 138 - 51)
Spec. for Leaded Red Brass (Hardware Bronze) Rod, Bar, and Shapes (B 140 - 51)
Spec. for Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 - 49)
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144 - 49)
Spec. for Leaded Red Brass and Leaded Semi-Red Brass Sand Castings (B 145 - 49)
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 49)
Spec. for High-Strength Yellow Brass (Manganese Bronze) and Leaded High-Strength Yellow Brass (Leaded Manganese Bronze) Sand Castings (B 147 - 49)
Spec. for Aluminum Bronze Sand Castings (B 148 - 49)
Spec. for Leaded Nickel-Brass (Leaded Nickel-Silver) and Leaded Nickel-Bronze (Leaded Nickel-Silver) Sand Castings (B 149 - 49)
Spec. for Copper-Alloy Condenser Tube Plates (B 171 - 51)
Spec. for Copper Bus Bars, Rods, and Shapes (B 187 - 51)
Spec. for Silicon-Bronze, and Silicon-Brass Sand Castings (B 198 - 49)

Withdrawal of Tentative:

Methods of Tension Testing of Copper and Copper-Alloy Rods, Bars, and Shapes (B 220 - 48 T)

Mr. Harnden then called on Mr. N. H. Murdza to present the following paper appearing as an appendix to the report:

Effect of Speed of Testing on the Tensile Properties of Copper and Copper-Base Alloys—N. H. Murdza.

Papers:

The Creep Properties of Sand-Cast Aluminum Materials 319-T71, 319-F and 356-T7—O. D. Sherby and John E. Dorn, presented from manuscript by F. M. Howell.

Plastic Stress-Strain Relations for Biaxial Tension and Variable Stress Ratios—Joseph Marin and L. W. Hu, presented from manuscript by Mr. Marin.

Restoration of Ductility of Cold-Worked Aluminum, Copper, and Low-Carbon Steel by Mechanical Treatment—H. N. Polakowski, presented from manuscript by E. J. Ripling.

Load-Deflection Relationships in Slow-Bend Tests of Charpy V-Notch Specimens—Richard Raring, presented by the author.

Effects of Machining Specimens on the Results of Tension Tests of Annealed Aluminum Alloys—G. W. Stickley and K. O. Bogardus, presented by Mr. Stickley.

TWENTY-THIRD SESSION—MARBURG LECTURE AND AWARDS

WEDNESDAY, JUNE 25, 4:00 P.M.

SESSION CHAIRMAN: PRESIDENT T. S. FULLER

Preceding the Marburg Lecture the President stated that the Board of Directors wished to recognize the forty-three years of service on the part of John K. Rittenhouse who retired on April 15 as Treasurer of the Society. In part of this recognition, the Board had elected Mr. Rittenhouse as Treasurer Emeritus. Mr. Rittenhouse acknowledged this recognition and expressed appreciation of his election as Treasurer Emeritus.

Edgar Marburg Lecture:

President Fuller presented Mr. R. C. McMaster, Supervisor of the Electrical Engineering Division of Battelle Memorial Institute, as the twenty-sixth Marburg lecturer, who then delivered a lecture on Non-Destructive Testing. In this lecture Mr. McMaster reviewed some of the background of Non-Destructive Testing since many non-destructive tests are among the earliest employed in the examination of materials and objects. He described the tests that fall under the category of non-destructive testing, discussing the utility and economic significance of the various tests and why it may be expected that non-destructive testing will play an even more important role in the future.

President Fuller expressed appreciation to Mr. McMaster for his very timely lecture on a most important subject and presented to him on behalf of the Society the Edgar Marburg Lecture Certificate.

Charles B. Dudley Medal:

The Twenty-fourth Award of the Charles B. Dudley Medal was made to Norman W. McLeod, Engineering Consultant, Department of Transport, Ottawa, Canada for his paper on "Application of Triaxial Testing to the Design of Bituminous Pavements," presented at the 1950 Annual Meeting and published in the Symposium on Triaxial Testing of Soils and Bituminous Mixtures."

Richard L. Templin Award:

The Seventh Richard L. Templin Award was made to Thomas J. Dolan, Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill., for his paper on "Electrically Excited Resonant-Type Fatigue Testing Equipment," presented at the 1951 Annual Meeting and published in the July 1951 issue of the ASTM BULLETIN.

FIFTIETH ANNIVERSARY DINNER

WEDNESDAY, JUNE 25, 6:00 P.M.

CHAIRMAN: PAST-PRESIDENT J. R. TOWNSEND

The New York Committee on Arrangements acted as official host for the Fiftieth-Anniversary Dinner at which there were some 460 members and guests present. The dinner was preceded by a cocktail party and there was entertainment and dancing afterwards. The dinner featured a talk by Dr. Detlev W. Bronk, President, National Academy of Sciences, and President of the Johns Hopkins University, who presented a most timely and thought-provoking address dealing with our present-day social, economic, and political situations.

TWENTY-FOURTH SESSION—SYMPOSIUM ON TESTING ADHESIVES FOR DURABILITY AND PERMANENCE

THURSDAY, JUNE 26, 9:30 A.M.

SESSION CHAIRMAN: A. G. H. DIETZ

SECRETARY: G. W. KOEHN

Committee D-14 on Adhesives:

Report presented by Frank W. Reinhart, chairman, and the following actions taken:

Accepted as Tentative:

Definitions of Terms Relating to Adhesives (D 907 - 52 T)

Adopted as Standard:

Definitions of Terms Relating to Adhesives (D 907 - 49 T)

Symposium on Testing Adhesives:[15]

The Effect of Specimen Structure in Permanence Tests on Wood Adhesives—Robert P. Hopkins, presented from manuscript by the author

Glass Adhesives—Frank Moser, presented from manuscript by the author.

Current Investigations of the Durability of Woodworking Adhesives—Richard F. Blomquist, presented from manuscript by the author.

Non-Destructive Determination of Mechanical Properties and Deterioration of Adhesives—Albert G. H. Dietz, Herman N. Bockstruck, and George Epstein, presented by Mr. Dietz.

Field and Laboratory Tests for Durability and Permanence—Adhesives Belonging to the Rubber-Resins System—John F. Anderson and L. F. Fiedler, presented from manuscript by Mr. Anderson.

Summary—R. C. Platow.

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[15] Issued as a separate publication, *STP No. 138.*

TWENTY-FIFTH SESSION—SESSION ON FACTORS AFFECTING THE DURABILITY OF CONCRETE

THURSDAY, JUNE 26, 9:30 A.M.

SESSION CHAIRMAN: STANTON WALKER

SECRETARY: L. E. GREGG

Significant Factors Affecting Concrete Durability—C. H. Scholer, presented from manuscript by the author.

Correlation of Sodium Sulfate Soundness of Coarse Aggregate with Durability and Compressive Strength of Air-Entrained Concrete—C. A. Vollick and E. I. Skillman, presented by W. H. Price.

Experimental Exposure of Concrete to Natural Weathering in Marine Locations—H. K. Cook, presented by the author.

Performance of Concrete Specimens During 10 Years Exposure to Severe Natural Weathering—W. J. McCoy and S. B. Helms, presented from manuscript by Mr. Helms.

Studies of Abnormal Expansion of Portland Cement Concrete—A. D. Conrow, presented from manuscript by the author.

TWENTY-SIXTH SESSION—TEXTILES

THURSDAY, JUNE 26, 9:30 A.M.

SESSION CO-CHAIRMEN: EPHRAIM FREEDMAN AND W. D. APPEL

Committee D-13 on Textile Materials:

Report presented by W. D. Appel, chairman, and the following actions taken:

Accepted as Tentative:

Methods of Testing Twine (From Bast and Leaf Fibers)

Sampling and Testing Staple Length of Wool in the Grease, with the second and third sentences in Section 4 (*b*) replaced by "It is unnecessary to cut the burlap."

Test for Shrinkage in Laundering of Cotton Knit Fabrics

Test for Shrinkage in Laundering of Rayon Knit Fabrics

Test for Flammability of Clothing Textiles

Tolerances for Acetate Yarns

Tolerances for Rayon Yarns

Tolerances for Nylon Yarns

Accepted as Tentative, Revisions in:

Definition of Terms Relating to Textile Materials (D 123 - 51 T): with the deletion of the definition for Skein Break Constant, and the revision of Skein, Numbering to read as follows "A skein having a prescribed length of yarn and used for the determination of linear density." Also in the definition of Tenacity, Breaking, change the word "constant" to "factor," and in the Note change the division sign to a solidus sign.

Spec. and Methods of Test for Asbestos Yarns (D 299 - 51 T)

Test for Resistance of Textile Fabrics to Water (D 583 - 50 T)

Test for Small Amount of Copper and Manganese in Textiles (D 377 - 50 T)

Testing and Tolerances for Cotton Yarns (D 180 - 49 T)

Testing and Tolerances for Continuous Filament Rayon and Estron Yarns (D 258 - 50 T): with the addition of a new Section 3 reading "3. Tolerances for Acetate, Rayon, and Nylon Yarns appear in the new Tentative Tolerances for Acetate Yarns, Rayon Yarns, and Nylon Yarns."

Spec. and Methods of Test for Asbestos Lap (D 1061 - 51 T)

Method of Test for Fastness of Colored Textiles to Light (D 506 - 50 T)

Rec. Practice for Planning Interlaboratory Testing of Textile Materials (D 990 - 49 T)

Methods of Test for Hard Scoured Wool in Wool in the Grease (Laboratory Scale Operations) (D 584 - 50)

Spec. for Textile Testing Machines (D 76 - 49),

Spec. and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 - 51)

Adopted as Standard:

Methods of Testing and Tolerances for Glass Yarn (D 578 - 50 T)

Method of Test for Vegetable Matter in Scoured Wool (D 1113 - 50 T)

Definition of Terms Relating to Textile Materials (D 123 - 51 T)

Method of Test for Yarn Number of Yarn from Fabrics (D 1059 - 49 T)

Method of Test for Colorfastness of Dyed Estron to Atmospheric Fumes (D 682 - 47 T)

Adopted as Standard, Revisions in:

Methods of Testing and Tolerances for Certain Wool and Part-Wool Fabrics (D 462 - 44)

Rec. Practice for a Universal System of Yarn Numbering (D 861 - 50)

Methods of Testing and Tolerances for Single Jute Yarn (D 541 - 49)

Methods of Testing and Tolerances for Jute Rove and Plied Yarn for Electrical and Packing Purposes (D 681 - 48)

Methods of Testing and Tolerances for Rope (Leaf and Bast Fibers) (D 738 - 46)

Methods of Testing and Tolerances for Spun. Twisted, or Braided Products Made from

Flax, Hemp, Ramie, or Mixture Thereof (D 739 - 46)

Methods of Testing and Tolerances for Single Jute Yarn (D 541 - 49)

Spec. and Methods of Test for Asbestos Tape for Electrical Purposes (D 315 - 49)

Spec. and Methods of Test. for Asbestos Roving for Electrical Purposes (D 375 - 49)

Methods of Testing Woven Asbestos Cloth (D 577 - 42)

Methods of Testing Asbestos Tubular Sleeving (D 628 - 44)

Withdrawal:

Withdrawal of the term "Estron" from all standards and definitions of Committee D-13, and substitution of the term "Acetate."

Reaffirmation of Standards:

Spec. and Methods for Osnaburg Cement Sacks (D 205 - 39)

Spec. for Numbered Cotton Duck and Army Duck (D 230 - 44)

Tests and Tolerances for Knit Goods (D 231 - 46)

Tests and Tolerances for Woven Tapes (D 259 - 44)

Tests for Maximum Residual Shrinkage in Silk and Rayon Woven Fabrics (D 413 - 39)

Tests for Rayon and Acetate Staple (D 540 - 44)

Tests and Tolerances for Certain Fine Staple Cotton Gray Goods (D 679 - 44)

Tests and Tolerances for Certain All-Cotton and Cotton and Rayon Fine Fancy Goods (D 680 - 44)

Papers:

An Engineering Approach to an Understanding of the Properties and Utilization of Textile Fabrics—Walter J. Hamburger, presented from manuscript by the author.*

Status of Synthetic Textiles—Their Promise for the Near Future—C. W. Bendigo, presented from manuscript by the author.*

Statistical Considerations in Fiber Research—Thomas F. Evans, presented from manuscript by the author.[16]

An Application of Statistics to Quality Control in the Textile Industry—Robert Jones, presented from manuscript by the author.[16]

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* Not published.

[16] Published in the 1952 Compilation of ASTM Standards on Textile Materials.

TWENTY-SEVENTH SESSION—SYMPOSIUM ON PLASTICS TESTING—PRESENT AND FUTURE

THURSDAY, JUNE 26, 2:00 P.M.

SESSION CO-CHAIRMEN: H. K. NASON AND C. R. STOCK

Committee D-6 on Paper and Paper Products:

Report presented by W. R. Willets, chairman, and the following actions taken:

Accepted as Tentative:

Test for Pinholes in Glassine and Other Greaseproof Papers

Test for Zinc and Cadmium in Paper

Methods for Contrast Gloss of Paper at 57.5 Deg

Test for Specular Gloss of Paper at 75 Deg

Test for Flat Crush of Corrugated Paperboard

Accepted as Tentative, Revisions in:

Test for Ply Adhesion of Paper or Vulcanized Fibre (D 825 - 48)

Test for Time of Penetration by Water of Sized Paper and Paper Products (Dry Indicator Method) (D 779 - 46)

Adopted as Standard:

Test for Organic Nitrogen in Paper and Paperboard (D 982 - 50 T)

Test for Peeling Resistance of Paperboard (D 1029 - 50 T)

Test for Fiber Analysis of Paper and Paperboard (D 1030 - 49 T)

Test for Static Bending Test for Corrugated Paperboard (D 1098 - 50 T)

Test for Water-Soluble Sulfates in Paper and Paperboard (D 1099 - 50 T)

Spec. for Filter Paper for Chemical Analysis (D 1100 - 50 T)

The committee withdrew from the report as preprinted the recommendation for adoption as standard of the Tentative Methods of Test for Fiber Analysis of Paper and Paperboard (D 1030 - 49 T)

Reaffirmation of Standards:

Test for Rosin in Paper and Paperboard (D 549 - 46)

Test for Opacity of Paper and Paper Products (D 589 - 44)

Test for Internal Tearing Resistance of Paper (D 689 - 44)
Test for Degree of Staining of Paper by Alkali (D 723 - 45)
Test for Surface Wettability of Paper (Angle-of-Contact Method) (D 724 - 45)
Test for Kerosine Number of Roofing and Flooring Felt by the Vacuum Method (D 727 - 45)
Test for Effect of Heating on Folding Endurance of Paper (D 776 - 46)
Test for Flammability of Treated Paper and Paperboard (D 777 - 46)
Test for Printing Ink Permeation of Paper (Castor Oil Test) (D 780 - 46)

Committee D-9 on Electrical Insulating Materials:

Report presented by A. H. Scott, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Orange Shellac and Other Indian Lacs for Electrical Insulation (D 784 - 50 T)
Methods of Testing Shellac Used for Electrical Insulation (D 411 - 50)
Methods of Testing Askarels (D 901 - 50 T)
Spec. for Absorbent Laminating Paper for Electrical Insulation (D 1080 - 49 T)
Test for Electrical Resistance of Insulating Materials (D 257 - 49)

Adopted as Standard:

Methods of Measuring Dimensions of Rigid Rods Used in Electrical Insulation (D 741 - 47 T)

Adopted as Standard, Revisions in:

Methods of Testing Laminated Tubes Used for Electrical Insulation (D 348 - 46)
Methods of Testing Laminated Round Rods Used for Electrical Insulation (D 349 - 46)
Methods of Measuring Dimensions of Rigid Tubes Used for Electrical Insulation (D 668 - 44)
Methods of Testing Pasted Mica Used in Electrical Insulation (D 352 - 49)

Withdrawal of Standard:

Methods of Testing Electrical Insulating Oils (D 117 - 43)

Committee D-10 on Shipping Containers:

Report presented in the absence of the chairman by L. C. Gilbert, and accepted as a report of progress.

Committee D-20 on Plastics

Report presented by G. M. Kline, chairman, and the following actions taken:

Accepted as Tentative:

Method for Measuring the Flow of Thermoplastics by Extrusion Plastometer: with editorial revisions
Test for Resistance of Plastic Films to Extraction by Chemicals

Accepted as Tentative, Revisions in:

Spec. for Ethyl Cellulose Molding Compounds (D 787 - 46 T)
Def. of Terms Relating to Plastics (D 883 - 51 T): with the deletion of the definitions for Alkyd Plastics, Extractibility, Hydrocarbon Plastics, Resin, Unsaturated Polyester Plastics, and Volatile Loss. Add the phrase "(not over 50 per cent)" at the end of the definitions for Furan Plastics and Lignin Plastics; also revise the definition of Thermoelasticity to read as follows: "Rubber-like elasticity by a rigid plastic resulting from an increase in temperature."
Method of Test for Tensile Properties of Plastics (D 638 - 49 T)

Adopted as Standard:

Test for Coefficient of Cubical Thermal Expansion of Plastics (D 864 - 45 T)
Test for Haze and Luminous Transmittance of Transparent Plastics (D 1003 - 49 T)

The committee withdrew from the report as preprinted the recommendation that the Tentative Method of Test for Flexural Properties of Plastics (D 790 - 49 T) be advanced to standard.

Reaffirmation of Standards:

Test for Acetone Extraction of Phenolic Molded or Laminated Products (D 494 - 46)
Test for Flammability of Plastics 0.050 in. and Under in Thickness (D 568 - 43)
Test for Flammability of Plastics over 0.050 in. in Thickness (D 635 - 44)
Test for Mar Resistance of Plastics (D 673 - 44)
Test for Coefficient of Linear Thermal Expansion of Plastics (D 696 - 44)
Test for Shear Strength of Plastics (D 732 - 46)

Symposium on Plastics Testing—Present and Future:[17]

Introductory Remarks—G. M. Kline
The Measurement and Significance of the Mechanical Strength Properties of Plastics—C. Howard Adams, presented from manuscript by the author.
Measurement of the Effect of Temperature on Some Physical Properties of Plastics—J. P.

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[17] Issued as a separate publication, *STP No. 132.*

Tordella, A. C. Webber, and E. B. Cooper, presented from manuscript by Mr. Tordella.

Measurement of Color, Gloss and Haze—H. K. Hammond, III, and G. W. Ingle, presented from manuscript by the authors.

The Effects of Molding Conditions Upon Permanence of Plastics—J. L. Williams and J. W. Mighton, presented by Mr. Mighton.

An Improved Fadeometer—Ladislav Boor and Seymour L. Trucker, presented from manuscript by Mr. Trucker.*

Residual Stresses in Phenolic Plastic—H. M. Quackenbos, Jr., and L. E. Welch, presented from manuscript by Mr. Quackenbos.

Summary—C. R. Stock.

Prediction of Creep Curves from Stress-Strain Data—Yoh-Han Pao and Joseph Marin, presented by Mr. Pao.

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* Published in ASTM BULLETIN No. 189, April, 1953, p. 38 (TP44).

TWENTY-EIGHTH SESSION—SYMPOSIUM ON DIRECT SHEAR TESTING OF SOILS[18]

THURSDAY, JUNE 26, 2:00 P.M.

SESSION CHAIRMAN: G. P. TSCHEBOTARIOFF

The authors at this session served as a panel, the symposium being conducted along the lines of a round-table discussion. Each author covered very briefly the subject matter of his paper, after which the sessions were thrown open to discussion, the authors being asked to answer the various questions raised. The following papers comprised the session:

The Place of Direct Shear Testing in Soil Mechanics—D. M. Burmister.

Use of Direct Shear Tests in Highway Design—E. S. Barber.

The Use of Direct Shear Tests in Earth Work Projects Under Construction—R. R. Proctor.

The Strength of Gravel in Direct Shear—R. G. Hennes.

A Direct Shear Test with Drainage Control—Donald Taylor.

The Use of the Direct Shear Testing Machine in Foundation Engineering Practice—F. J. Converse.

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[18] Issued as a separate publication, *STP No. 131.*

TWENTY-NINTH SESSION—SYMPOSIUM ON RECENT DEVELOPMENTS IN THE EVALUATION OF NATURAL RUBBER[19]

THURSDAY, JUNE 26, 2:00 P.M.

SESSION CO-CHAIRMEN: SIMON COLLIER AND NORMAN BEKKEDAHL

Introduction—by Norman Bekkedahl.

Technical Classification of Crude Natural Rubber—R. G. Newton, presented from manuscript by L. Mullins.

Quantitative Procedures for the Determination of Dirt in Crude Natural Rubber—R. P. Stock, C. O. Miserentino, C. B. McKeown, J. J. Hoesly, R. T. LaPorte, and G. H. Wallace, presented from manuscript by Mr. Miserentino.

Mooney Viscosity Measurements in Determining Processibility of Technically Classified Rubbers—Rolla H. Taylor, and A. G. Veith, presented from manuscript by Mr. Veith.

Technically Classified Rubber: The Non-Rubber Content and the Measurement of Cure Rate—A. G. Veith, presented from manuscript by the author.

Vulcanization Characteristics of Natural Rubbers—Robert D. Stiehler and Frank L. Roth, presented from manuscript by Mr. Stiehler.

Preparation of a Standard Natural Rubber—E. M. McColm, presented from manuscript by the author.

Some Aspects of the Testing of Crude Rubber and Crude Rubber Compounds—Leslie V. Cooper, presented from manuscript by T. M. Kersker.

Rubber Evaluations with an Instron Testing Machine—S. D. Gehman, and R. P. Clifford, presented from manuscript by Mr. Gehman.

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[19] Issued as a separate publication, *STP No. 136.*

THIRTIETH SESSION—REPORT SESSION

THURSDAY, JUNE 26, 5:00 P.M.

SESSION CHAIRMAN: D. E. PARSONS

Committee C-2 on Magnesium Oxychloride and Oxysulfate Cements:

Report presented by L. S. Wells, chairman, and the following actions taken:

Adopted as Standard:

Methods of Chemical Analysis of Magnesium Sulfate, Technical Grade (C 244 – 50 T)
Methods of Chemical Analysis of Magnesium Chloride (C 245 – 50 T)
Methods of Physical Testing of Magnesia for Magnesium Oxychloride Cement (C 246 – 50 T)
Test for Ignition Loss and Active Calcium Oxide in Magnesium Oxide for Use in Magnesium Oxychloride Cements (C 247 – 50 T)
Test for Bulk Density of Magnesium Oxychloride Cements (C 248 – 50 T)
Slump Test for Field Consistency of Magnesium Oxychloride Cements (C 249 – 50 T)
Methods of Mixing Magnesium Oxychloride Cement Compositions with Gauging Solution (for Preparation of Specimens for Laboratory Tests) (C 251 – 50 T)
Test for Linear Contraction of Magnesium Oxychloride Cements (C 252 – 50 T)
Test for Linear Change of Magnesium Oxychloride Cements (C 253 – 50 T)
Test for Setting Time of Magnesium Oxychloride Cements (C 254 – 50 T)
Test for Consistency of Magnesium Oxychloride Cements by the Flow Table (C 255 – 50 T)
Test for Flexural Strength of Magnesium Oxychloride Cements (Using Simple Bar with Two-Point or Single-Point Loading) (C 256 – 50 T)
Test for Compressive Strength of Magnesium Oxychloride Cements (C 257 – 50 T)
Spec. for Field Determination of Specific Gravity of Gauging Solutions for Magnesium Oxychloride Cements (C 250 – 50 T)

Committee C-3 on Chemical-Resistant Mortars:

Report presented by F. O. Anderegg, chairman, and the following action taken:

Accepted as Tentative:

Spec. for Sulfur Mortars

Committee C-8 on Refractories:

Report presented in the absence of the chairman by L. C. Gilbert and the following actions taken:

Accepted as Tentative:

Test for Disintegration of Fireclay Refractories in an Atmosphere of Carbon Monoxide

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Refractories (C 71 – 51)
Test for Crushing Strength and Modulus of Rupture of Insulating Fire Brick at Room Temperature (C 93 – 46)

Adoption as Standard, Revisions in:

Methods of Chemical Analysis of Refractory Materials (C 18 – 51)
Method for Basic Procedure in Panel Spalling Test for Refractory Brick (C 38 – 49)
Panel Spalling Test for High Duty Fireclay Brick (C 107 – 47)
Panel Spalling Test for Super Duty Fireclay Brick (C 122 – 47)
Panel Spalling Test for Fireclay Plastic Refractories (C 180 – 49)

Reaffirmation of Standards:

Testing Refractory Brick Under Load at High Temperature (C 16 – 49)
Test for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick (C 20 – 46)
Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 46)
Test for Sieve Analysis and Water Content of Refractory Materials (C 92 – 46)
Test for Reheat Change of Refractory Brick (C 113 – 46)
Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 49)
Test for Size and Bulk Density of Refractory Brick (C 134 – 41)
Test for Combined Drying and Firing Shrinkage of Fireclay Plastic Refractories (C 179 – 46)
Test for Reheat Change of Insulating Fire Brick (C 210 – 46)
Standard Symbols for Heat Transmission (C 108 – 46)

Committee C-11 on Gypsum:

Report presented by L. S. Wells, chairman, and the following action taken:

Adopted as Standard, Revisions in:

Methods of Testing Gypsum and Gypsum Products (C 26 – 50): with a change in Test

Specimen 25, as preprinted. At the end of the fifth line in the second paragraph add the following: "2 ± 0.005 in. for new molds, or . . . ."

Spec. for Gypsum Wall Board (C 36 – 50)

Spec. for Gypsum Sheathing Board (C 79 – 50)

Committee C-13 on Concrete Pipe:

Report presented in the absence of the chairman by L. C. Gilbert and the following actions taken:

Adopted as Standard, Revision in:

Spec. for Concrete Sewer Pipe (C 14 – 41)

Spec. for Reinforced Concrete Sewer Pipe (C 75 – 41)

Spec. for Reinforced Concrete Culvert Pipe (C 76 – 41)

Spec. for Concrete Irrigation Pipe (C 118 – 39)

Committee C-14 on Glass and Glass Products:

Report presented in the absence of the chairman by L. C. Gilbert and the following action taken:

Adopted as Standard:

Definitions of Terms Relating to Glass and Glass Products (C 162 – 49 T)

Committee C-16 on Thermal Insulating Materials:

Report presented in the absence of the chairman by L. C. Gilbert and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Mineral Wool Molded-Type Pipe Insulation (for Elevated Temperatures) (C 281 – 51 T)

Test for Compressive Strength of Preformed Block Type Thermal Insulation (C 165 – 45)

Adoption as Standard, Revisions in:

Test for Bulk Density of Thermal Insulating Cement (C 164 – 44)

Test for Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 – 45)

Editorial Changes Accepted in:

Test for Flexural Strength of Preformed Block Type Thermal Insulation (C 203 – 51)

Committee C-17 on Asbestos-Cement Products:

Report presented in absence of the chairman by L. C. Gilbert and the following action taken:

Accepted as Tentative:

Spec. for Asbestos-Cement Pressure Pipe

Committee C-18 on Natural Building Stones:

Report presented in absence of the chairman by L. C. Gilbert and the following action taken:

Adopted as Standard, Revisions in:

Test for Modulus of Rupture of Natural Building Stone (C 99 – 47)

Flexure Testing of Slate (Modulus of Rupture, Modulus of Elasticity) (C 120 – 48)

Committee C-19 on Structural Sandwich Constructions:

Report presented by E. W. Kuenzi, chairman-elect, and the following action taken:

Accepted as Tentative:

Tension Test in Flatwise Plane of Sandwich Constructions

Committee C-22 on Porcelain Enamel:

Report presented in absence of the chairman by L. C. Gilbert and accepted as a report of progress.

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by W. T. Pearce, chairman, and the following actions taken:

Accepted as Tentative:

Test for Common Properties of Certain Pigments

Test for Color of Clear Liquids (Platinum-Cobalt Scale)

Test for Temperature-Change Resistance of Clear Nitrocellulose Lacquer Films Applied to Wood

Test for Fineness of Dispersion of Pigment-Vehicle Systems

Test for Crushing Resistance of Glass Spheres

Test for Sieve Analysis of Glass Spheres

Test for Measurement of Wet Film Thickness of Paint, Varnish, Lacquer, and Related Products: with the insertion after Sections 4 (*a*) and 8 (*a*) of the following paragraph: "Although this procedure refers to measurements on test panels, the same technique may be used in the field or shop on commercial articles provided the substrate is not distorted to an extent which would affect the measurements."

Accepted as Tentative, Revisions in:

Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding (D 969 – 48 T)

Adoption as Standard:

Spec. for Raw Castor Oil (D 960 – 48 T)
Spec. for Secondary Butyl Acetate (85 to 88 per cent Grade) (D 966 – 48 T)
Spec. for Secondary Butyl Alcohol (D 1007 – 49 T)
Methods of Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products (D 609 – 50 T)
Test for Total Nitrogen in Resins for Surface Coatings (D 1013 – 49 T)
Test for Total Chlorine in Polyvinyl Chloride Polymers and Copolymers Used for Surface Coatings (D 1156 – 51 T)
Test for Night Visibility of Traffic Paints (D 1011 – 49 T)

Adopted as Standard, Revisions in:

Test for No-Pick-Up Time of Traffic Paints (D 711 – 51)
Definitions of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 – 51)
Methods of Chemical Analysis of Dry Cuprous Oxide and Copper Pigments (D 283 – 51)
Test for Phthalic Anhydride Content of Alkyd Resins and Resin Solutions (D 563 – 49)

The committee withdrew from the report as preprinted the recommendation for immediate adoption of revisions in the Standard Spec. for Industrial 90 Benzene for Use in Paint, Varnish, Lacquer, and Related Products (D 361 – 36); Standard Spec. for Industrial Grade Toluene for Use in Paint, Varnish, Lacquer, and Related Products (D 363 – 36); and the Standard Spec. for Industrial Grade Xylene or Solvent Naphtha for Use in Paint, Varnish, Lacquer, and Related Products (D 364 – 36).

Withdrawal of Standards:

Test for Alkalinity or Acidity of Pigments (D 278 – 31)
Spec. for Butyl Propionate (90 to 93 per cent Grade) (D 320 – 40)
Spec. for Ethyl Lactate (Synthetic) (D 321 – 40)

Reaffirmation of Standards:

Oil Absorption of Pigments (D 281 – 31)
Coarse Particles in Pigments, Pastes and Paints (D 185 – 45)
Chemical Analysis of White Linseed Oil Paint (D 215 – 41)
Chemical Analysis of Dry Red Lead (D 49 – 44)
Hygroscopic Moisture (and Other Matter Volatile Under the Test Conditions) in Pigments (D 280 – 33)
Analysis of Barium Sulfate Pigments (D 715 – 45)
Analysis of Mica Pigments (D 716 – 45)
Analysis of Magnesium Silicate Pigment (D 717 – 45)
Analysis of Aluminum Silicate Pigment (D 718 – 45)
Spectral Characteristics and Color of Objects and Materials (D 307 – 44)
Test for Relative Dry Hiding Power of Paints (D 344 – 39)
Relative Dry Hiding Power of White Pigments in Linseed Oil Vehicle (D 406 – 39)
Conducting Road Service Tests on Traffic Paint (D 713 – 46)
Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus (D 522 – 41)
Spec. for Ethyl Acetate (85 to 88 per cent Grade) (D 302 – 33)
Normal Butyl Acetate (88 to 92 per cent Grade) (D 303 – 40)
Butanol (Normal Butyl Alcohol) (D 304 – 45)
Amyl Acetate (Synthetic) (85 to 88 per cent Grade) (D 318 – 39)
Amyl Acetate (Synthetic) (D 319 – 40)
Acetone (D 329 – 33)
Ethylene Glycol Monobutyl Ether (D 330 – 35)
Ethylene Glycol Monoethyl Ether (D 331 – 35)
Acetate Ester of Ethylene Glycol Monoethyl Ether (95 to 96 per cent Grade) (D 343 – 35)
Amyl Acetate Made With Fusel Oil (85 to 88 per cent Grade) (D 554 – 39)
Dibutylphthalate (D 608 – 43)
Isopropyl Acetate (D 657–44)
Methyl Ethyl Ketone (D 740–46)
Isopropyl Alcohol (D 770–46)

Accepted for Publication as Information Only:

Test for Flash Point of Volatile Solvents by the Tag Open-Cup Apparatus, with editorial changes.

Committee D-5 on Coal and Coke:

Report presented by W. A. Selvig, chairman, and accepted as a report of progress.

The committee withdrew from the report as preprinted the recommendation for immediate adoption of revisions in the Standard Method of Test for Free-Swelling Index of Coal (D 720 – 46).

Committee E-5 on Fire Tests of Materials and Construction:

Report presented by R. C. Corson, secretary, and accepted as a report of progress.

The recommendation for the immediate adoption of revisions in the Standard Methods of Fire Tests of Building Construction and Materials (E 119 – 50) was withdrawn by the committee as a result of discussion from the floor, and with subsequent motion the recommendation was referred back to the committee for further consideration.

Committee E-6 on Methods of Testing Construction:

Report presented by J. A. Liska, chairman, and the following action taken:

Adopted as Standard, Revisions in:

Methods of Testing Truss Assemblies (E 73 – 48 T)

THIRTY-FIRST SESSION—REPORT SESSION

THURSDAY, JUNE 26, 5:00 P.M.

SESSION CHAIRMAN: N. L. MOCHEL

Committee B-1 on Wires for Electrical Conductors:

Report presented by W. R. Hibbard, vice-chairman, in the absence of the chairman, and the following actions taken:

Accepted as Tentative:

Method for Determination of Cross-Sectional Area of Stranded Conductors
Spec. for Zinc-Coated (Galvanized) Steel Core Wire (With Coatings Heavier than Standard Weight) for Aluminum Conductors, Steel Reinforced (ACSR)
Spec. for Three-Quarter Hard Aluminum Wire for Electrical Purposes

Accepted as Tentative, Revisions in:

Spec. for Hard-Drawn Copper Wire (B 1 – 51 T)
Spec. for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 – 51 T)
Spec. for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (B 173 – 51 T)
Spec. for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 – 51 T)
Spec. for Soft or Annealed Copper Wire (B 3 – 45)
Spec. for Tinned Soft or Annealed Copper Wire for Electrical Purposes (B 33 – 51)
Spec. for Lead-Coated Soft Copper Wire for Electrical Purposes (B 189 – 51)
Spec. for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 – 50 T)
Spec. for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (B 232 – 50 T)
Spec. for Standard Weight Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) (B 245 – 49 T)

Adopted as Standard, Revisions in:

Spec. for Medium-Hard-Drawn Copper Wire (B 2 – 49)
Spec. for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 50)
Spec. for Bronze Trolley Wire (B 9 – 49)
Spec. for Copper Trolley Wire (B 47 – 49)
Spec. for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (B 48 – 51)
Spec. for Hot-Rolled Copper Rods for Electrical Purposes (B 49 – 50)
Spec. for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 49)
Spec. for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (B 116 – 49)
Spec. for Cored, Annular, Concentric-Lay-Stranded Copper Conductors (B 226 – 50)
Spec. for Hard-Drawn Copper Covered Steel Wire (B 227 – 49)
Spec. for Concentric-Lay-Stranded Copper Covered Steel Conductors (B 228 – 49)
Spec. for Concentric-Lay-Stranded Copper and Copper Covered Steel Composite Conductors (B 229 – 49)
Spec. for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (B 231 – 49)
Spec. for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 – 49)

Committee B-2 on Non-Ferrous Metals and Alloys:

Report presented by G. Howard Lefevre, secretary, and the following actions taken:

Accepted as Tentative:

Spec. for Iodide Titanium
Spec. for Titanium Strip, Sheet, Plate, Bar, Tube, Rod, and Wire
Spec. for Titanium Ingot

Adopted as Standard:

Spec. for Metallic Antimony (B 237 – 49 T)
Spec. for Classification of Coppers (B 224 – 48 T)

The committee withdrew from the report as preprinted the recommendation for advancement to standard of the Tentative Specifications for Fire-Refined Casting Copper (B 72 – 47 T).

Reaffirmation of Standards:

Spec. for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5 – 43)
Spec. for Electrolytic Cathode Copper (B 115 – 43)
Spec. for Rolled Zinc (B 69 – 39)
Spec. for Nickel (B 39 – 22)
Spec. for Lead-Coated Copper Sheets (B 101 – 40)

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented in the absence of the chairman by J. S. Pettibone, and accepted as a report of progress.

Committee B-4 on Electrical Heating, Resistance, and Related Alloys:

Report presented in the absence of the chairman by J. S. Pettibone, and the following actions taken:

Accepted as Tentative:

Test for Relative Thermionic Emissive Properties of Materials Used in Electron Tubes
Spec. for Sag of Tungsten Wire
Spec. for High-Resistivity, Low-Temperature Coefficient Wire
Spec. for Round Chromium-Copper Wire for Electronic Devices

Accepted as Tentative, Revisions in:

Methods of Testing Sleeves and Tubing for Radio Tube Cathodes (B 128 – 48 T)

Adopted as Standard, Revisions in:

Spec. for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical-Heating Elements (B 82 – 46)
Spec. for Drawn or Rolled Alloy, 60 per cent Nickel, 16 per cent Chromium, and Balance Iron, for Electrical-Heating Elements (B 83 – 46)
Test for Temperature-Resistance Constants of Alloy Wires for Precision Resistors (B 84 – 45)

Accepted for Publication as Information Only:

Methods for Chemical Analysis of Electronic Nickel

Committee B-6 on Die-Cast Metals and Alloys:

Report presented in the absence of the chairman by W. Babington, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Aluminum-Base Alloy Die Castings (B 85 – 50 T)
Spec. for Zinc-Base Alloys in Ingot Form for Die Castings (B 240 – 49 T)

Adopted as Standard:

Spec. for Magnesium-Base Alloy Die Castings (B 94 – 49 T)

Adopted as Standard, Revisions in:

Spec. for Zinc-Base Alloy Die Castings (B 86 – 48)

The committee withdrew from the report as preprinted the recommendation for a change in Table I of the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 – 48).

Spec. for Lead- and Tin-Base Alloy Die Castings (B 102 – 48)
Spec. for Copper-Base (Brass) Alloy Die Castings (B 176 – 50)

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by L. V. Williams, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Codification of Light Metals and Alloys, Cast and Wrought
Spec. for Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications
Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications

Accepted as Tentative, Revisions in:

Spec. for Aluminum-Base Alloy Sand Castings (B 26 – 50 T)
Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 – 51 T)
Spec. for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 50 T)
Spec. for Aluminum and Aluminum-Alloy Sheet and Plate for Use in Pressure Vessels (B 178 – 51)
Spec. for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 – 51 T)
Spec. for Aluminum-Alloy Drawn Seamless Tubes (B 210 – 50 T)
Spec. for Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 – 49 T)
Spec. for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 49 T)
Spec. for Aluminum-Alloy Extruded Tubes (B 235 – 50 T)
Spec. for Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 – 48 T)

Adopted as Standard, Revisions in:

Spec. for Magnesium Ingot and Stick for Remelting (B 92 – 45)

Reaffirmation of Standards:

Spec. for Aluminum Ingots for Remelting (B 24 – 46)
Test for Dielectric Strength of Anodically-Coated Aluminum (B 110 – 45)
Test for Sealing of Anodically-Coated Aluminum (B 136 – 45)
Test for Weight of Coating on Anodically-Coated Aluminum (B 137 – 45)

Committee B-8 on Electrodeposited Metallic Coatings:

Report presented, in the absence of the chairman, by J. S. Pettibone, and accepted as a report of progress.

It was announced that the committee had withdrawn from the report as preprinted the recommendations for revision of nine tentatives and standards to give coating thickness values in mils and microns rather than in decimal inches.

Committee B-9 on Metal Powders and Metal Powder Products:

Report presented by W. A. Reich, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Evaluating the Microstructure of Apparent Porosity in Cemented Carbides

Adopted as Standard:

Spec. for Sintered Metal Powder Structural Parts (B 222 – 50 T)

THIRTY-SECOND SESSION—CONCRETE

THURSDAY, JUNE 26, 8:00 P.M.

SESSION CHAIRMAN: K. B. WOODS

Committee C-1 on Cement:

Report presented by R. R. Litehiser, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Method for the Potential Alkali Reactivity of Cement Aggregate Conbinations (C 227 – 51 T)
Test for Time of Setting of Hydraulic Cement in Mortar (C 229 – 51 T)
Spec. for Flow Table for Use in Tests of Hydraulic Cement (C 230 – 49 T)
Test for Bleeding of Cement Pastes and Mortars (C 243 – 50 T)
Spec. for Natural Cement (C 10 – 49 T)

Adopted as Standard:

Method of Test for Time of Setting of Hydraulic Cement by Vicat Needle (C 191 – 51 T)

Adopted as Standard, Revisions in:

Test for Compressive Strength of Hydraulic Cement Mortars (C 109 – 50)
Test for Autoclave Expansion of Portland Cement (C 151 – 49)
Spec. for Portland Cement (C 150 – 49): special permission was obtained from the Executive Committee of the Board of Directors to add a recommendation for the advancement to standard of an additional revision of C 150. This revision was issued January 5, 1952, and revises the time of setting requirements in Table II, and changes the wording in the second sentence of footnote *b*.

Withdrawal of Standard:

Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles (C 191 – 49)

Committee C-7 on Lime:

Report presented, in the absence of the chairman, by Chairman-elect J. A. Murray, and the following actions taken:

Adopted as Standard:

Spec. for Quicklime for Calcium Carbide Manufacture (C 258 – 50 T)
Spec. for Hydrated Lime for Grease Manufacture (C 259 – 50 T)

Reaffirmation of Standards:

Spec. for Quicklime for Structural Purposes (C 5 – 26)
Spec. for Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (C 45 – 25)
Spec. for Quicklime for Sulfite Pulp Manufacture (C 46 – 27)
Spec. for Hydrated Lime for Varnish Manufacture (C 47 – 27)
Spec. for Quicklime and Hydrated Lime for Silica Brick Manufacture (C 49 – 42)
Test for Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (C 50 – 27)

Committee C-9 on Concrete and Concrete Aggregates:

Report presented by K. B. Woods, chairman, and the following actions taken:

Accepted as Tentative:

Test for Potential Reactivity of Aggregates, Chemical Test
Tests for Resistance of Concrete Specimens to Freezing and Thawing

Separate tentative methods will be published to cover the three types outlined:

Rapid Freezing and Thawing in Water
Rapid Freezing in Air and Thawing in Water
Slow Freezing and Thawing in Water or Brine

Test for Flexural Strength of Concrete Using a Simple Beam with Center-Point Loading
Rec. Practice for Petrographic Examination of Aggregates for Concrete
Descriptions of Constituents of Natural Mineral Aggregates

Accepted as Tentative, Revisions in:

Testing Air-Entraining Admixtures for Concrete (C 233 – 50 T)
Spec. for Air-Entraining Admixtures for Concrete (C 260 – 50 T)
Test for Fundamental Transverse Frequency of Concrete Specimens for Calculating Young's Modulus of Elasticity (Sonic Method) (C 215 – 51 T)
Test for Water Retension Efficiency of Methods for Curing Concrete (C 156 – 44 T)
Test for Air Content of Freshly Mixed Concrete by the Pressure Method (C 231 – 49 T)
Test for Volume Change of Cement Mortar and Concrete (C 157 – 43)
Spec. for Concrete Aggregates (C 33 – 49)
Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 – 49)
Method of Sampling Fresh Concrete (C 172 – 44)
Test for Cement Content of Hardened Portland-Cement Concrete (C 85 – 42)

Adopted as Standard, Revisions in:

Test for Measuring Mortar-Making Properties of Fine Aggregate (C 87 – 47)
Method of Slump Test for Consistency Portland-Cement Concrete (C 143 – 39)

Reaffirmation of Standards:

Test for Unit Weight of Aggregate (C 29 – 42)
Test for Voids for Aggregate in Cement (C 30 - 37)
Test for Coal and Lignite in Sand (C 123 – 44)
Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 – 39)
Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42)
Specific Gravity and Absorption of Fine Aggregates (C 128 – 42)
Sieve Analysis of Fine and Coarse Aggregates (C 136 – 46)
Weight per Cubit Foot, Yield, and Air Content (Gravimetric) of Concrete (C 138 – 44)
Test for Clay Lumps in Aggregates (C 142 – 39)
Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 – 46)

Sanford E. Thompson Award:

Mr. Woods then presented the Tenth Sanford E. Thompson Award to H. F. Gonnerman and William Lerch, Assistant to the Vice President for Research and Development, and Administrative Assistant respectively, Portland Cement Assn., Chicago, Ill., for their paper on "Changes in Characteristics of Portland Cement as Exhibited by Laboratory Tests over the Period 1904 to 1950" published as separate technical publication No. 127. This paper was presented at the 1951 Annual Meeting of the Society held in Atlantic City, N. J., June 21–25.

Committee C-12 on Mortars for Unit Masonry:

Report presented, in the absence of the chairman, by F. O. Andregg, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Mortar for Unit Masonry (C 270 - 51 T)
Spec. for Aggregate for Masonry Mortars (C 144 - 44)

Committee C-15 on Manufactured Masonry Units:

Report presented, in the absence of the chairman, by M. H. Allen, secretary, and the following actions taken:

Accepted as Tentative, Revision in:

Spec. for Structural Clay Facing Tile (C 212 - 50 T)

Adopted as Standard. Revisions in:

Spec. for Concrete Building Brick (C 55 - 37)
Spec. for Hollow Load-Bearing Concrete Masonry Units (C 90 - 44)
Spec. for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 - 39)
Spec. for Structural Clay Load-Bearing Wall Tile (C 34 - 50)
Spec. for Solid Load-Bearing Concrete Masonry Units (C 145 - 40)
Spec. for Structural Clay Non-Load-Bearing Tile (C 56 - 50)
Spec. for Structural Clay Floor Tile (C 57 - 50)
Methods of Sampling and Testing Concrete Masonry Units (C 140 - 39)
Methods of Sampling and Testing Structural Clay Tile (C 112 - 36)

Editorial Changes Accepted in:

Spec. for Building Brick (C 62 - 50)
Spec. for Structural Clay Non-Load-Bearing Tile (C 56 - 50)
Spec. for Structural Clay Floor Tile (C 57 - 50)
Spec. for Ceramic Glazed Structural Clay Facing Tile, Facing Brick and Solid Masonry Units (C 126 - 50 T)

Committee D-4 on Road and Paving Materials:

Report presented by C. E. Proudley, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 544 - 52 T)

Accepted as Tentative, Revisions in:

Spec. for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (D 947 - 49 T)
Spec. for Asphaltic Mixtures for Sheet Asphalt Pavements (D 978 - 49 T)
Spec. for Crushed Stone, Crushed Slag, and Gravel for Single Bituminous Surface Treatment (D 1139 - 50 T), with the change in the second sentence of Section 4 as preprinted revised to read as follows:

(The purpose of) a single surface treatment is (to place the aggregate) *a wearing surface of bituminous material and aggregate in which the aggregate is placed* uniformly over the bituminous material in a *single* layer (approximately one piece of aggregate in thickness), *the thickness of which approximates the nominal maximum size of the aggregate.*

Test for Compressive Strength of Bituminous Mixtures (D 1074 - 49 T)
Methods of Sampling Bituminous Materials (D 140 - 49 T)
Spec. for Bituminous Mixing Plant Requirements (D 995 - 51)

Adopted as Standard:

Test for Bitumen (D 4 - 49 T)
Test for Resistance to Plastic Flow of Fine-Aggregate Bituminous Mixtures (D 1138 - 50 T)

Adopted as Standard, Revisions in:

Definition of Terms Relating to Materials for Roads and Pavements (D 8 - 51)
Test for Distillation of Tar Products Suitable for Road Treatment (D 20 - 30)
Test for Penetration of Bituminous Materials (D 5 - 49)
Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements, and Soft Tar Pitches (D 70 - 27)
Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (D 71 - 27)

Reaffirmation of Standards:

Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 42)
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42)
Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 46)
Test for Abrasion of Rock by Use of the Deval Machine (C 2 - 33)
Test for Toughness of Rock (D 3 - 18)
Test for Ductility of Bituminous Materials (D 113 - 44)
Test for Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 - 46)
Test for Sieve Analysis of Mineral Filler (D 546 - 41)

Test for Standard Volume Correction Table for Tar and Coal Tar Pitch (D 633 - 44)

Withdrawal of Standards:

Test for Determination of Bitumen (D 4 - 42)

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented, in the absence of the chairman, by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Spec. for Asphalt Insulating Siding Surfaced with Mineral Granules
Spec. for Asphalt-Base Emulsion for Use as Protective Coatings for Built-Up Roofs
Method of Testing Asphalt Insulating Siding Surfaced with Mineral Granules

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Bituminous Waterproofing and Roofing Materials (D 1079 - 50 T)
Methods of Sampling Bituminous Materials (D 140 - 49 T)

Adopted as Standard:

Spec. for Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 - 50 T)

Reaffirmation of Standards:

Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 44)
Spec. for Asphalt-Saturated Roofing Felt for Use in Waterproofing and Constructing Built-Up Roofs (D 226 - 47)
Test for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 47)
Spec. for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and Constructing Built-Up Roofs (D 250 - 47)
Spec. for Asphalt for Use in Constructing Built-Up Coverings (D 312 - 44)
Spec. for Asphalt for Dampproofing and Waterproofing (D 449 - 49)
Spec. for Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 49)
Spec. for Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 - 47)
Test for Testing and Sampling Films Deposited from Bituminous Emulsions (D 466 - 42)
Testing Emulsified Asphalts (D 244 - 49)
Test for Standard Volume Correction Table for Tar and Coal Tar Pitch (D 633 - 44)

Editorial Changes Accepted in:

Spec. for Asphalt Shingles Surfaced with Mineral Granules (D 225 - 51)
Spec. for Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 - 50 T)
Spec. for Asphalt Roofing Surfaced with Mineral Granules (D 249 - 50 T)

Papers:

Efflorescence—F. O. Anderegg, presented by the author.[20]
Proposed Methods for Determining the Sulfate Resistance of Portland Cements—David Wolochow, presented from manuscript by the author.
Cracking in Masonry Caused by Expansion of Mortar—J. W. McBurney, presented by the author.
Chemical Test for Alkali Reactivity of Pozzolans—Richard C. Mielenz, K. T. Greene, E. J. Benton, and Fred H. Geler, presented from manuscript by Mr. Mielenz.
A General Analytic Solution for Mohr's Envelope—Glenn Balmer, (Presented by title only).

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[20] Published in the ASTM BULLETIN No. 185, October 1952, p. 39 (TP155).

THIRTY-THIRD SESSION—CORROSION AND CREEP OF METALS

THURSDAY, JUNE 26, 8:00 P.M.

SESSION CHAIRMAN: SAM TOUR

Committee A-3 on Cast-Iron:

Report presented by J. S. Vanick, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Chilled and White Iron Castings: revised as preprinted by the omission of the first sentence of Section 7.

Reaffirmation of Standards:

Spec. for Cast Iron Pit-Cast Pipe for Water or Other Liquids (A 44 - 41)
Spec. for Gray Iron Castings (A 48 - 48)
Spec. for Cast Iron Soil Pipe and Fittings (A 74 - 42)
Spec. for Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A 126 - 42)
Rec. Practice for Torsion Test of Cast Iron (A 260 - 47)
Spec. for Cast Iron Culvert Pipe (A 142 - 38)
Spec. for Lightweight and Thin-Sectioned Gray Iron Castings (A 190 - 47)
Test for Compression Testing of Cast Iron (A 256 - 46)

Def. of Terms Relating to Cast Iron (A 196 – 47)
Rec. Practice for Evaluating the Microstructure of Graphite in Gray Iron (A 247 – 47)

Committee A-5 on Corrosion of Iron and Steel:

Report presented by T. R. Galloway, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for 1.25-oz Ordered Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets

Accepted as Tentative, Revisions in:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 – 50 T)

Adopted as Standard:

Spec. for Zinc-Coated (Galvanized) High-Tensile Steel Telephone and Telegraph Line Wire (A 326 – 49 T)

Adoption as Standard, Revisions in:

Spec. for Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Wire (A 111 – 51)

Reaffirmation of Standards:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 – 33)
Spec. for Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized After Weaving (A 117 – 33)
Spec. for Zinc-Coated Steel Wire Strand ("Galvanized" and Class A) ("Extra Galvanized") (A 122 – 41)
Spec. for Zinc-Coated Steel Wire Strand (Class B and C Coatings) (A 218 – 41)
Test for Weight of Coating on Zinc Coated (Galvanized) Iron or Steel Articles (A 90 – 39)
Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron and Steel Articles (A 239 – 41)
Rec. Practice for Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A 143 – 46)

Committee A-10 on Iron-Chromiun, Iron-Chromium-Nickel, and Related Alloys:

Report presented, in the absence of the chairman, by M. A. Cordovi, secretary, and the following actions taken:

Adopted as Standard, Revisions in:

Spec. for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 47)
Spec. for Seamless Austenitic Chromium Nickel Steel Still Tubes for Refinery Service (A 271 – 47)

The recommendation for a proposed Tentative Specification for Iron-Chromium and Iron-Chromium-Nickel Alloy Tubular Centrifugal Castings for General Applications, as preprinted in the report, was withdrawn by the committee.

Papers:

A Method of Evaluating Corrosion by Molten Metals—M. A. Cordovi, presented from manuscript by the author.
Atmospheric Corrosion of Steel Wires—A. P. Jahn, presented from manuscript by the author.
A Cyclic Humidity Accelerated Corrosion Test for Sheet Steel—A. J. Opinsky, R. F. Thomson, and A. L. Boegehold, presented from manuscript by Mr. Opinsky.[21]
Atmospheric Corrosion of Low Alloy Steels—H. R. Copson, presented by the author.
Creep-Tension Relations at Low Temperatures—J. D. Lubahn, presented by the author.
The Influence of Periodic Overstressing on the creep Properties of Several Heat-Resistant Alloys—G. J. Guarnieri and L. A. Yerkovich, presented by Mr. Yerkovich.

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[21] Published in the ASTM BULLETIN No. 187, January 1953, p. 47 (TP1).

THIRTY-FOURTH SESSION—SYMPOSIUM ON EXCHANGE PHENOMENA IN SOILS

FRIDAY, JUNE 27, 9:30 A.M.

SESSION CHAIRMAN: R. C. MIELENZ

Committee D-18 on Soils for Engineering Purposes:

Report presented by E. J. Kilcawley, chairman, and the following actions taken:

Adopted as Standard:

Test for Specific Gravity of Soils (D 854 – 50 T)

Reaffirmation of Standards:

Test for Preparing Soil Samples for Mechanical

Analysis and Determination of Subgrade Soil Constants (D 421 - 39)
Test for Liquid Limit of Soils (D 423 - 39)
Test for Plastic Limit and Plasticity Index of Soils (D 424 - 39)
Test for Centrifuge Moisture Equipment of Soil (D 425 - 39)
Test for Field Moisture Equipment of Soils (D 426 - 39)
Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 - 44)
Wetting and Drying Test of Compacted Soil Cement Mixtures (D 559 - 44)
Test for Shrinkage Factors of Soils (D 427 - 39)
Freezing and Thawing Test of Compacted Soil Cement Mixtures (D 560 - 44)

Symposium on Exchange Phenomena in Soils:[22]

Ion Exchange in Relation to Some Properties of Soil-Water Systems—Ralph E. Grim, presented from manuscript by E. J. Kilcawley.
Cation Exchange Capacity in Loess and Its Relation to Engineering Properties—Donald T. Davidson and John B. Sheeler, presented by Mr. Davidson.
Job Experience with Exchange Phenomena Involving Inorganic and Organic Ions—Hans F. Winterkorn, presented from manuscript by the author.
Surface-Chemical Properties of Clay Minerals and Soils—Hans F. Winterkorn and Gerhard Schmid, presented from manuscript by Mr. Winterkorn.
Some Effects of Treating Expansive Clays with Calcium Hydroxide—Irving Goldberg and Alexander Klein, presented from manuscript by H. E. Davis.
Summary—E. F. Preece.

THIRTY-FIFTH SESSION—REPORT SESSION

FRIDAY, JUNE 27, 11:30 A.M.

SESSION CHAIRMAN: A. E. MILLER

Committee D-2 on Petroleum Products and Lubricants:

Report presented by W. T. Gunn, Secretary, in the absence of the chairman, and the following actions taken:

Accepted as Tentative:

Def. and Specs. for Farm Tractor Fuels
ASTM-IP Petroleum Measurement Tables
Test for Calibrating Liquid Containers, Section A—Upright Tanks
Analysis of Calcium and Barium Petroleum Sulfonates
Measurement of Density and Specific Gravity of Liquids to the Fifth Place (Bingham Pycnometer Method)
Measurement of Refractive Index and Refractive Dispersion of Hydrocarbon Liquids
Mercaptan Sulfur in Jet Fuels (Color-Indicator Method)

Accepted as Tentative, Revisions in:

Spec. for Gasoline (D 439 - 50 T): with the proposed research octane number requirements in *Table I*, as preprinted, revised from "76 to 85" to "78 or 85," for Types A and B gasoline.

Also change footnote "*d*" to read: "(*d*). The technical data available do not afford an adequate basis for specifying maximum sulfur content at the present time (1952). Gasolines containing up to 0.25 per cent sulfur (ASTM D 90 - 50 T) are distributed within the United States."

Spec. for Aviation Gasolines (D 910 - 51 T)
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 48 T)
Test for Water and Sediment by Means of Centrifuge (D 96 - 50 T)
Sampling Petroleum and Petroleum Products (D 270 - 50 T), with the procedure for sampling liquified petroleum gases accepted as tentative subject to the concurrence of Committee D-3 on Gaseous Fuels.
Test for Kinematic Viscosity (D 445 - 46 T), with a change in Section 4 (*c*). Table I: delete the second, third, and fourth thermometers from the table. Also delete the reference note at the bottom of the table. (Refer to Appendix V of the 1951 Report of Committee D-2.) Also delete the supplement from this method.
Test for Distillation of Plant Spray Oils (D 447 - 51 T)
Test for Unsulfonated Residue of Petroleum Plant Spray Oils (D 483 - 51 T)
Test for Carbon Residue of Petroleum Products (Ramsbottom Coking Method) (D 524 - 51 T)
Test for Rust-Preventing Characteristics of Steam-Turbine Oil in the Presence of Water (D 665 - 50 T)

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[22] Issued as a separate publication, *STP No. 142.*

Test for Chlorine in Lubricating Oils and Greases by the Bomb Method (D 808 - 51 T)
Methods of Analysis of Petroleum Sulfonates (D 855 - 46 T)
Test for Normal Pentane and Benzene Insolubles in Used Lubricating Oils (D 893 - 50 T)
Test for Neutralization Value (Acid and Base Numbers) by Color-Indicator Titration (D 974 - 51 T)
Classification of Diesel Fuel Oils (D 975 - 51 T): with the deletion of the proposed revision of Footnote "*b*," and of the proposed paragraph on "Cloud Point," as preprinted.
Test for Determination of Purity from Freezing Points (D 1016 - 51 T)
Method of Gaging Petroleum and Petroleum Products (D 1085 - 50 T)
Method of Measuring the Temperature of Petroleum and Petroleum Products (D 1086 - 50 T)
Volume Calculations and Corrections in the Measurement of Petroleum and Petroleum Products (D 1087 - 50 T)
Test for Bromine Number of Petroleum Distillates (Color-Indicator Method) (D 1158 - 51 T)
Test for Bromine Number of Petroleum Distillates (Electrometric Method) (D 1159 - 51 T)
Test for Reduced Pressure Distillation of Petroleum Products (D 1160 - 51 T)
Test for Existent Gum in Gasoline (Air-Jet Evaporation Method) (D 381 - 50)
Test for Cone Penetration of Lubricating Grease (D 217 - 48)

Adopted as Standard:

Test for Acetylene in Polymerization Grade Butadiene by Silver Nitrate Method (D 1020 - 49 T)
Test for Separation of Residue from Butadiene (D 1023 - 49 T)
Test for Nonvolatile Residue of Polymerization Grade Butadiene (D 1025 - 49 T)
Test for Acidity of Residue from Distillation of Gasoline and Petroleum Solvents (D 1093 - 50 T)

Adopted as Standard, Revisions in:

Spec. for Stoddard Solvent (D 484 - 40): with the description of the pipet added to the first paragraph describing the flask and changed to read: "and pipet standardized to agree with the flask."
Test for Flash Point by Tag Closed Tester (D 56 - 51)
Test for Distillation of Gasoline, Naptha, Kerosine, and Similar Petroleum Products (D 86 - 46)
Test for Precipitation Number of Lubricating Oils (D 91 - 40)
Test for Flash and Fire Points by Means of Open Cup (D 92 - 46)
Test for Flash Point by Means of the Pensky-Martens Closed Tester (D 93 - 46)
Test for Sulfur in Petroleum Products and Lubricants by the Bomb Method (D 129-51)
Test for Distillation of Gas Oil and Similar Distillate Fuel Oils (D 158 - 41)
Test for Carbon Residue of Petroleum Products (Conradson Carbon Residue) (D 189 - 46): with the deletion of the proposal to omit the note under the title of the method
Test for Distillation of Natural Gasoline (D 216 - 40)
Test for Distillation of Crude Petroleum (D 285 - 41)
Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287 - 39)
Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 - 49)
Test for Neutralization Value (Acid and Base Numbers) by Electrometric Titration (D 664 - 51)
Test for Saponification Number of Petroleum Products by Potentiometric Titration (D 939 - 50)
Def. of Terms Relating to Petroleum (D 288 - 51)

Withdrawal of Tentatives and Standards:

Method of Chemical Analysis for Phosphorus in Lubricating Oils (D 809 - 50 T)
Factors and Tables for Volume Correction and Specific Gravity Conversion of Liquefied Petroleum Gases (D 1090 - 50 T)
Abridged Volume Correction Table for Petroleum Oils (D 206 - 36)
Test for Oil Content of Paraffin Wax (D 721 - 47)

Accepted for Publication as Information Only:

Test for Free and Corrosive Sulfur in Petroleum Products (D 130 - 50 T), proposed revision of Sections 3 (*a*) and 6 (*b*) and Fig. 1.
Supporting Data for the adoption of the 1948 CFR Redesignated High-Speed Crankcase as optional equipment for use with methods of test contained in the "ASTM Manual of Engine Test Methods for Rating Fuels."
Test for API Gravity of Petroleum and its Products by Hydrometer.
Test for Specific Gravity of Petroleum and its Products by Hydrometer.
Test for Hydrocarbon Types in Jet Propulsion Fuels, Florescent Indicator Chromatographic Method.
Test for Water in Petroleum Products and Other Bituminous Materials.
Polarographic Method of Test for Tetraethyllead in Gasoline.
Test for Vapor Pressure of Petroleum Products.
Test for Oil Content of Petroleum Waxes.

The committee withdrew from the report the recommendation for the publication as information of the Proposed "Recommended Practices for Applying Precision Data Given in ASTM Methods of Test for Petroleum Products and Lubricants."

Committee D-3 on Gaseous Fuels:

Report presented in the absence of the chairman by R. E. Hess, and the following action taken:

Adopted as Standard:

Tests for Specific Gravity of Gaseous Fuels (D 1070 – 49 T), as revised

Committee D-11 on Rubber and Rubber-like Materials:

Report presented by Simon Collier, chairman, and the following actions taken:

Accepted as Tentative:

Test for Low-Temperature Compression Set of Vulcanized Elastomers, with editorial changes
Test for Hardness of Rubber (D 314 – 39)

Accepted as Tentative, Revisions in:

Methods of Sample Preparation for Physical Testing of Rubber Products (D 15 – 50 T), with editorial changes
Spec. for Friction Tape for General Use for Electrical Purposes (D 69 – 48 T)
Test for Compression Set of Vulcanized Rubber (D 395 – 49 T), with the table in Section 11 (*b*) changed to read as follows:

Durometer Hardness Number	Thickness of Spacer Bar, in.	Deflection, approximate percentage of original thickness
Up to 44, incl.,	0.300 ± 0.001	40
45 to 64 incl.	0.350 ± 0.001	30
65 to 84 incl.	0.375 ± 0.001	25
85 and over	0.400 ± 0.001	20

Testing Rubber Insulated Wire and Cable (D 470 – 50 T)
Test for Changes in Properties of Rubber, and Rubber-like Materials in Liquids (D 471 – 51 T)
Heat Aging of Vulcanized Natural or Synthetic Rubber by Test Tube Method (D 865 – 50 T)
Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus (D 1053 – 51 T), with editorial changes

Adopted as Standard, Revisions in:

Method of Air Pressure Heat Test of Vulcanized Rubber (D 454 - 50)
Test for Accelerated Aging of Vulcanized Rubber by the Oxygen-Pressure Method (D 572 – 50)
Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 – 48)

Withdrawal of Tentative:

Spec. for Natural Rubber Cups for Use in Hydraulic Actuating Cylinders (D 818 – 45 T)

Committee D-12 on Soaps and Other Detergents:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Adopted as Standard:

Spec. for Sodium Bicarbonate (D 928 – 47 T)

Adopted as Standard, Revisions in:

Spec. for Palm Oil Solid Soap (D 535 – 41)
Spec. for Palm Oil Chip Soap (D 536 – 42)
Spec. for Ordinary Bar Soap (D 497 – 39)
Def. of Terms Relating to Soaps and Other Detergents (D 459 – 51)

Reaffirmation of Standards:

Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 46)
Chemical Analysis of Soaps Containing Synthetic Detergents (D 820 – 46)
Chemical Analysis of Sulfonated and Sulfated Oils (D 500 – 45)
Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 – 45)
Test for Particle Size of Soaps and Other Detergents (D 502 – 39)
Spec. for Built Soap, Powdered (D 533 – 44)
Spec. for Alkaline Soap Powder (D 534 – 42)
Spec. for Soda Ash (D 458 – 39)
Spec. for Modified Soda (Sesquicarbonate Type) (D 457 – 39)
Spec. for Sodium Metasilicate (D 537 – 41)
Spec. for Sodium Sesquisilicate (D 594 – 41)
Spec. for Trisodium Phosphate (D 538 – 44)

Editorial Changes Accepted in:

Spec. for Caustic Soda (D 456 – 39)
Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 – 45)
Spec. for Liquid Toilet Soap (D 799 – 51)

Accepted for Publication as Information Only:

Methods of Test for Surface and Interfacial Tension of Solutions of Surface-Active Agents
Method of Test for Rinsing Properties of Metal Cleaners
Method of Test for Buffering Action of Metal Cleaners
Method of Total Immersion Corrosion Test for Soak Tank Metal Cleaners

Committee D-15 on Engine Antifreezes:

Report presented by H. R. Wolf, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Method for Sampling and Preparing Aqueous Solutions of Engine Antifreeze (D 1176 - 51 T)

Test for Freezing Point of Aqueous Engine Antifreeze Solutions (D 1177 - 51 T)

Committee D-16 on Industrial Aromatic Hydrocarbons:

Report presented in the absence of the chairman by P. J. Smith, and accepted as a report of progress.

Committee D-17 on Naval Stores:

Report presented by V. E. Grotlisch, chairman, and the following actions taken:

Adopted as Standard:

Def. of Terms Relating to Naval Stores and Related Products (D 804 - 51 T): with the definition of sulfate pine oil further revised by changing the phrase "the conversion of wood to paper" to "the digestion of wood;" also with a revision, not preprinted, of the definition of tall oil rosin to read as follows by the addition of the italicized words: Tall Oil Rosin.—Rosin remaining after the removal of *substantially all of* the fatty acids from tall oil by fractional distillation or other suitable means. Such rosin shall have the characteristic form, appearance, and other physical and chemical properties normal for other kinds of rosin. *The fatty acid content shall not exceed 5 per cent.*

Adopted as Standard, Revisions in:

Methods of Sampling and Grading Rosin (D 509 - 45): with the addition of the following at the end of Footnote 4, as preprinted: "Information on sources of supply of secondary standards may be obtained from the Naval Stores Division."

Tests for Toluene Insoluble Matter in Rosin (D 269 - 30)

Accepted for Publication as Information:

Spec. for Dipentene: with the following change in Table I: transfer the maximum requirement for flash point of 110 F, to the minimum column. Also change the maximum requirement for dissolved water, per cent by weight from 2.0 to 0.02.

Spec. for Pine Oil

Spec. for Rosin: with the Note under Section 2 transferred to (*j*) of Section 3. Revise the note to read as follows: Note.—The fatty acid content of tall oil rosin is computed from the difference between the total acid number and the rosin acid number, according to the following equation:

$$\text{Fatty Acids, per cent,} = \frac{AN - RN \times 0.282 \times 100}{56.1}$$

where:

AN = Total acid number, and

RN = Rosin acid number.

Committee D-21 on Wax Polishes and Related Materials:

Report presented in the absence of the chairman by P. J. Smith, and accepted as a report of progress.

THIRTY-SIXTH SESSION—SYMPOSIUM ON TEST METHODS FOR PROCESS CONTROL IN CERAMIC WHITEWARES

FRIDAY, JUNE 27, 2:30 P.M.

SESSION CHAIRMAN: C. G. HARMAN

Committee C-21 on Ceramic Whiteware:

Report presented by J. H. Koenig, chairman, and accepted as a report of progress.

The committee withdrew from the report as preprinted the recommendation for revision in the Tentative Definition of Terms Relating to Ceramic Whitewares (C 242 - 50 T).

Symposium on Test Methods for Process Control in Ceramic Whitewares:[23]

Introduction—C. G. Harman.

The Status and the Importance of Terminology of Ceramic Whitewares—Arthur S. Watts, presented from manuscript by Ralston Russell.

Possibilities for Adapting Research Tools for Process Control Evaluations—John H. Koenig and E. J. Smoke, presented from manuscript by Mr. Smoke.

Report on Round Robin Investigation of Modulus of Rupture Tests of Ceramic Specimens—Rolland R. Roup, presented from manuscript by H. Z. Schofield.

Report on Determination of Sub-Sieve Particle Size—C. J. Koenig and Kent Smalley, presented from manuscript by Mr. Koenig.

Evaluation of the Critical Properties of Clay—T. A. Klinefelter, presented from manuscript by H. P. Hamlin.

Summary—C. G. Harman.

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[23] Not published.

"SOME GRATIFYING RESULTS"

Annual Address by the President

T. S. Fuller,[1]

June 24, 1952

I am happy today to note so many of our friends from foreign lands participating in this the Fifty-Fifth Annual Meeting of our Society and the fiftieth Annual Meeting since incorporation. Let me assure our guests that they are most welcome.

The American Society for Testing Materials was legally incorporated, through the granting of a charter, on June 3, 1902, under the laws of the Commonwealth of Pennsylvania, and this charter was unanimously adopted by the membership at the Fifth Annual Meeting held June 12–14 at Atlantic City.

All things are temporal. We have been privileged to live in a period of rapid change and great progress in many ways. Fifty years ago few homes enjoyed telephones and electric lights, and none of us at that time, of course, were tempted to while away our time with radio and television programs. Automatic heating and air conditioning of homes were nonexistent.

Populationwise the United States has increased from 76,094,134 to 150,697,000, the national income from $88,517,000,000 to $239,000,000,000, and the national debt from $1,263,000,000, or $16.50 per capita, to $257,357,000,000, or $1696 per capita.

Whether or not all of these items indicate progress may well be a matter of opinion and a subject for debate. They do, howeve, provide substantial proof of the great changes—social, economic, and technical—which have taken place over the 50-year period.

In 1902 our Society had been in active existence for four years as the American Section of the International Association for Testing Materials. During the Society's third Annual Meeting, October 25-26-27, 1900, the Chairman, Professor Mansfield Merriman, as pointed out in the October, 1951, Bulletin, spoke forthrightly of his dissatisfaction with the then existing conditions. Professor Merriman said in part—"It may here be plainly stated that the policy of the International Association in regard to publications is not satisfactory to many American members. The proceedings of the Council meetings are not published, no financial statements are given out, and practically nothing is known of the work of the technical committees." After discussing further details of the publication problem, Professor Merriman said "In addition to the above I have to acknowledge the receipt, on July 27, 1900, of a typewritten copy of the minutes of the Council meeting held ten months previously, namely, on September 25 and 26, 1899.

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[1] Engineer in Charge of Works Laboratory, General Electric Co., Schenectady, N. Y.

"Attention may also properly be called to the fact that no statements regarding the expenditures of the Association have even been made, as far as I am able to learn. As the American Section has regularly transmitted to the International Council $1.50 per year for each of its members, it would seem that such statements are due us. In my opinion it becomes a question to be carefully considered as to whether this state of affairs ought to be continued indefinitely."

Well and forcibly did Professor Merriman express his concern over the then-existing conditions. Well did his colleagues respond, and well have Professor Merriman's successors carried the torch down through the ensuing 50 years, opening new avenues of knowledge along the way and well will future generations carry on the work of our Society into paths now unknown, because the work of groups such as ours, founded on sound principles and with worthy aims, can never be retarded but must continue toward the ultimate goal always to be approached but never to be attained.

The first proposed specification of our Society was issued in 1900 and adopted in 1901 and covered steel for bridges and ships, buildings, boiler plates and rivet steels, rails, plice bars, axles, steel ties, forgings, castings, and wrought irons. Today we have 1800 standards comprising 10,000 pages and printed in eight volumes.

In 1901, the roll of members included 168 names. Today, 51 years later, we find a membership of over 7000.

The first technical committee, A-1 on Steel, was organized in 1898. Fifty-four years later the Year Book shows 74 technical committees and 1120 subcommittees and subgroups. One but has to turn each year to the annual report of the Board of Directors for a complete statement of our Society's financial position. These data offer eloquent testimony to the excellence of Professor Merriman's judgment in 1902.

The first standards approved by our Society were concerned with metals. In 1902 there were 10 such standards. Ten years later, in 1912, there were 50 standards dealing with metals and 12 concerned with nonmetallics, or a ratio of approximately 41:1 in favor of the metals. In 1952, however, the situation has changed to the point where there are 526 metallic standards and 1284 dealing with nonmetallics or a shift in the ratio to 1:2.4 in favor of the nonmetallics.

Thus did our Society at the outset concern itself with the properties of metals. However, just as science has reached out into new fields, so has our Society correspondingly broadened its scope, to the end that specifications and methods of test for all types of materials used by modern industry have been provided.

These most gratifying results of our Society have been made possible by the committee organization of the type now in use. As each of you so well know, each committee provides an open forum where producers and consumers meet for discussion and solution of problems of mutual concern. No other type of organization could, in my opinion, function so well.

The 50-year period with which we are concerned today has witnessed remarkable improvement in the science of testing. In the early 1900's engineering concepts and the materials then existent made necessary the use of low design stresses. As new materials became available and as the complexity of the information required by the engineering profession, increased, so did the philosophy of testing change to keep abreast of the demands.

Two phases, namely, the evaluation of materials and the control of quality, are involved in the science of testing. The evaluation of the properties of materials requires research and development programs which may extend over considerable periods of time. Control of quality, because of the volume of material involved, must be accomplished by reasonably short-time tests. It has been in the interest of saving time that many of the improvements in testing machines have been added.

The autographic and recording devices and other refinements have greatly facilitated the accuracy and convenience of the Universal Testing Machine.

Many modern engineering designs require information on high temperature, tensile, creep, rupture, and fatigue properties of metals. Others call for information on these same properties at extremely low temperatures.

Non-destructive testing, which was practically non-existent fifty years ago, is essential to modern technology. Radiography, magnetic particle testing, and examination by ultrasonic means constitute extremely important activities of many laboratories.

The versatility of the ultrasonic test is apparent when it is realized that, like its counterpart, radar, an ultrasonic beam can be made to travel in a direction perpendicular to the surface of the object, angularly through the object, or along the surface. The frequency of the ultrasonic vibration can be varied over wide limits—for example, one-half to five megacycles—and thus in itself act as a selector to detect flaws of a given magnitude. The ability of most materials to conduct sound easily permits inspection of material irrespective of size or thickness. The ability of flaws to reflect the high-frequency sound beam back to the source permits internal inspection to be carried out from that surface which is particularly convenient to the operator.

The application of this versatile tool has made possible the examination of the internal condition of wrought parts with the same thoroughness that has been used for years in the X-raying of cast parts.

The crystal balls of history, with the exception of those of Jules Verne and Leonardo da Vinci, have not been noted for accuracy. Statistically the odds are overwhelmingly discouraging toward any prediction which I might venture. Consequently, I shall adhere strictly to the projection of current activities at current rates of increase. By so doing one comes up with numbers of imposing proportions, and one wonders how executives of the 2000 A.D. era will cope with the problems of finance and printing.

The annual budget on which the Society is currently operating is $629,000.

The receipts of the Society in 1902 were $408 and the disbursements $609. A previous cash balance, however, helped out, leaving a cash balance in June, 1902, of $87. As of the same date, however, an unpaid bill item of $91 must have been very disturbing to the auditors. On March 8, 1902, the Acting Secretary was authorized to spend a sum not exceeding $25 per month for clerical assistance.

Should the rate of increase of the annual operating expenses, which has been in effect for the past ten years, continue, such expenses at the end of another half century would be of the order of 2.3 million. Unfortunately the measuring stick, the dollar, has been very unstable during this ten-year period, having depreciated during that time by 43 per cent. Perhaps one of the most important services which this society might attempt to perform would be to assist in the evolution of a standard dollar.

Applying the same line of reasoning to the number of standards and number of pages embodied in those standards, 50 years hence there will be 4600 standards requiring 28,000 pages.

Judging by past performance, the number of members in the year 2002 will be 18,000.

However, it is not merely the matter of physical growth which is of consequence. These growths are a measure, a means perhaps, of evaluating what is even more significant—the importance of the Society's role in the nation's economy today. I very much doubt if our founding fathers, even though they recognized the importance of standard specifications when they set up the new American Society for Testing Materials, had any inkling of how important a part the Society would play or the recognized position it would take. I look for the further enhancement of that position in our free economy.

Most certainly the most important problem facing the world today involves a search for a means of providing mutual understanding among nations, yes among all the peoples of the earth, that they may live together in harmony and peace. This problem is as old as the world and perhaps it may never be solved, but we have the right to hope, and it seems to me that there is a potential opportunity for good for a better understanding among people through "standardization."

It has been my privilege to have met many engineers from foreign lands who have been intensely interested in "standardization," and I have found them, with few exceptions, to be the same kind of persons we are in ASTM. They think as we do and their interests are similar. They smoke the same kind of tobacco and have the same virtues and the same sins.

So in bringing this brief address to a close, I appeal to engineers of all lands, because of their mutuality of interests, to work for understanding not only in the field of standardization but also in politics, economics, and all other fields, to the end that our hope, that we may contribute our "widow's mite" to a permanent peace, may be nearer justification.

ANNUAL REPORT OF THE BOARD OF DIRECTORS

In this, the Board's report for 1952, the Anniversary Year of the Society, no attempt is made to chart the growth of the Society during the past fifty years. This was done to some extent in the Board's report two years ago and is covered from time to time in the ASTM BULLETIN and elsewhere. The report does propose, however, to review the activities that have taken place during the Anniversary Year and for which the Board is responsible, that is, how well the purposes for which the Society was founded are being carried out. This is represented by the activities of the technical committees, the Standards publications, the holding of meetings and discussions, and the publication of technical papers and reports. These are all discussed in later sections.

The membership record is an indication of the extent to which those interested are being reached and enrolled in the Society's activities (present membership, 7250). The financial operations provide a somewhat similar index. Comparisons can be made, if desired, with the record of earlier years to see how far the Society has progressed. The report will also serve as a base for projecting future growth and activities.

The increased activity has required an increased staff (now 56 staff members), which in turn necessitates enlarged headquarters. Such extension in headquarters space can now be provided through the acquisition of additional ground to the rear of the present building.

Much of the activity during the past year has been in preparation for the Fiftieth Anniversary Annual Meeting, including the many technical sessions participated in by many visitors from abroad. These preparations occupied much of the attention of the Executive Secretary, including a trip to Europe during the closing months of 1951. In looking forward to this meeting, the Board is greatly saddened by the sudden death of the Executive Secretary, C. L. Warwick, which occurred on the evening of April 23. At its meeting held shortly after his death, the Board adopted the following resolution in his memory:

——C. LAURENCE WARWICK——

1889–1952

With profound sorrow the Board of Directors of the American Society for Testing Materials records the sudden death on April 23, 1952 of its long-time Executive Secretary, C. Laurence Warwick. His passing was a distinct shock and a deep personal loss to his large number of friends and associates in the Society. His influence and leadership in the development of the Society was probably greater than that of any other individual, coupled with a keen realization of the great significance and importance of ASTM work in our scientific and industrial structure.

The Staff, the Board of Directors, the Society, and American science and industry have lost an outstanding leader.

Born in Philadelphia in 1889, Mr. Warwick attended the Philadelphia public schools, graduating from Central Manual Training School. In 1909 he received his B.S. degree from the University of Pennsylvania in Civil Engineering, and some years later the C.E. degree. He continued at the University as an instructor and subsequently became an Assistant Professor of structural engineering. During his undergraduate days he had become closely associated with Dr. Edgar Marburg who was ASTM's first secretary from 1902 to 1918.

While on the University faculty, Mr. Warwick assisted Dr. Marburg in ASTM Staff work and was named Assistant Secretary in 1917. In 1919, following the death of Dr. Marburg, he was elected Secretary-Treasurer, a title he held until 1946 when the title of the chief administrative officer was changed to that of Executive Secretary, at which time he was elected to that office.

Mr. Warwick contributed largely to the technical activities of the Society. One of his first technical services was to succeed Dr. Marburg as secretary of Committee A-1 on Steel. He was at various times a member in either an active or advisory capacity of other technical committees. One of his notable contributions and one in which he took especially keen interest was his service as chairman of the Administrative Committee on Papers and Publications, which committee is responsible for the technical programs of the Society's meetings. The research aspects of the Society's work also interested him greatly, so he served as secretary of the Administrative Committee on Research, the committee that supervises these activities.

Mr. Warwick represented the Society in a number of activities, including the ASME Advisory Board on Engineering Index, the Industry Advisory Committee of the Federal Specifications Board, the American Association for the Advancement of Science, and others. Special reference should be made to his participation in the work of the American Standards Association. From its inception, he had an active, influential part and made many contributions in the interest of that organization. For a period he was chairman of the Conference of Executives of Organization Members of ASA (CEOM).

Always vitally concerned and interested in assisting the technical branches of the Government and the Armed Forces with their problems, particularly along standardization lines, he had ample opportunity to render valuable service. At the time of his death he was serving as chairman of the ASTM Ordnance Advisory Committee, a post he considered one of his most important responsibilities. In April, 1941, he was asked by the Office of Production Management to come to Washington to assist in establishing the conservation work of the War Production Board. He headed the Specifications Branch of the Conservation Division and directed the National Emergency Steel Specifications Project which proved so effective in conserving critical metals.

More recently Mr. Warwick had much to do with the present contract between the Office of Defense Mobilization and ASTM.

In his official capacity he prepared a large number of reports and technical papers, and frequently spoke on engineering materials, standardization, research, and related topics.

The Board of Directors is acutely conscious of its great loss in Mr. Warwick's death. The Fiftieth Anniversary year of the Society was one in which he would have derived great satisfaction. The officers and members for a long time to come will derive inspiration from his deep devotion to his duties, the intensive manner in which these were carried out, and the spirit which motivated his long-time work in the Society.

The officers of the Society record their appreciation of his notable services and many contributions, pay homage to him, and extend to Mrs. Warwick, to his mother, and to his daughter and two sons their heartfelt sympathy.

A special committee on commemoration has been appointed by the Board to consider suitable ways of memoralizing Mr. Warwick.

Technical Activities

The activities of the technical committees have continued at a high level during the year. The standardization work naturally has received primary consideration in view of the contemplated appearance in 1952 of the triennial Book of Standards, since the committees will wish to have the standards and tentatives appear in their latest form in this new edition. The record of recommendations acted upon by the Administrative Committee on Standards is quite impressive. If all of these recommendations were concentrated in the Annual Meeting it would bulk up the matters to be handled at the Annual Meeting to almost impossible proportions, aside from the fact that the availability of the Administrative Committee procedure has expedited the appearance of a number of new tentatives and proposed revisions of standards. The annual report of this Administrative Committee, covering not only a record with respect to the actions on recommendations dealing with standards but also consideration of new projects, is attached to this report (see Appendix II).

The research activities of the technical committees are important not only from the point of view of developing new data with respect to materials but more particularly in supplying the necessary background for development of new test procedures and in the refinement of existing procedures. All such activities fall under the purview of the Administrative Committee on Research. The report of this committee, however (which appears as Appendix III), refers more particularly to support which the Research Committee is giving to certain specific projects and to the assembling of a list of problems on which the technical committees believe that work is desirable. A compilation of these suggested research projects has been published and the list will be extended from time to time.

The report of the Administrative Committee on Simulated Service Testing, covering briefly the matters upon which the committee has been engaged, is attached as Appendix V.

New Activities:

Reference was made in the report a year ago to the organization of a new Committee D-23 on Cellulose and Cellulose Derivatives. Organization of this committee was effected at a meeting on September 24 with F. A. Simmonds and W. W. Becker continuing as temporary chairman and temporary secretary, respectively. It is planned to elect permanent officers at a meeting scheduled for the early fall. At the organization meeting, the following scope was adopted which was subsequently approved by the Board:

> The definition of terms, and the study and formulation of test methods and specifications covering cellulose for chemical conversion and cellulose derivatives, these activities to be coordinated in cooperation with relevant committees in ASTM and outside organizations.

As a matter of record, it is reported that the organization of Committee E-10 on Radioactive Isotopes was completed during the 1951 Annual Meeting under the temporary chairmanship of G. G. Manov, with D. M. McCutcheon as temporary secretary. The following statement of scope has been approved for the committee:

> (*a*) To promote the knowledge of the use of radioactive isotopes in materials testing;
>
> (*b*) To aid and advise the technical committees of the Society in the preparation of methods and development of instruments of testing in the field of radioactive isotopes;
>
> (*c*) To prepare methods of testing using radioactive isotopes, not coming within the scope of any other technical committee;
>
> (*d*) To standardize the nomenclature and definitions used in or relating to testing methods or instruments using radioactive isotopes in cooperation with other committees;
>
> (*e*) To perform such other functions as may advance, improve, standardize and unify the procedures of materials testing by means of radioactive isotopes.

A proposal was received during the summer of 1951 that the Society organize a new committee on Mass Spectrometry. Accordingly, a conference on the subject was held at Society Headquarters on January 14, 1952. It was the consensus of this conference that the interest in this subject was such that a forum should be provided for the exchange of information and that a technical committee in

ASTM would be the logical way of providing such a forum. This committee would at the same time serve to coordinate the work that has been under way or contemplated in several ASTM committees. This would suggest that the committee should be in the E group in the technical committee structure. The Board of Directors, upon giving consideration to the recommendation of this conference, authorized the establishment of a new Committee E-14 on Mass Spectrometry. The proposed scope of this new committee, which scope was subsequently adopted at the organization meeting of Committee E-14, is set forth as follows:

> Promotion of knowledge and advancement of the art of mass spectrometry by:
>
> (*a*) Coordinating scientific applications and methods of analysis based on mass spectrometry.
>
> (*b*) Sponsoring meetings at which scientific papers relative to mass spectrometry may be presented and discussed.
>
> (*c*) Standardizing nomenclature relating to mass spectrometry.
>
> (*d*) Initiating, sponsoring, and reporting work in the field of mass spectrometry, without prejudice to the jurisdiction of other technical committees over their respective materials.
>
> It is the objective of the committee to encourage participation on the widest possible basis of individuals interested in mass spectrometry, in order to coordinate work and promote the exchange of information in the field. Emphasis will be placed on presentation, at national meetings, of papers on all phases of mass spectrometry, with subsequent publication in the most appropriate medium.

The organization meeting of Committee E-14 was held on March 6 in conjunction with the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy. W. S. Young was elected as chairman and J. G. Hutton, secretary.

With the organization of these new committees during the year, the total number of ASTM technical committees is now 73. This statement alone does not give a complete picture of the growth among the technical committees, however, since the activities of a number of them have been extended, as will be noted from the following section of this report.

Committee Scopes and Jurisdictions:

An increase in scope has been authorized for Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, having in mind the alloys in the high-temperature field sometimes referred to, although inexactly, as "jet alloys." The statement of scope of Committee A-10 will now read as follows, the italicized words being new:

> In general, Commitee A-10 has jurisdiction over the classification, specification requirements, methods of test, questions of utility and related subjects pertaining to those iron-base ***and other chromium-bearing*** alloys termed "stainless," "rustless," ***or*** "***heat resistant,***" whose primary characteristic is resistance to corrosive attack, elevated temperatures, or both.

It may later be found that work on these high-temperature alloys would warrant the organization of an entirely new committee.

In connection with the study that has been given to the scopes of committees during the year, it developed that the scope of Committee B-2 on Non-Ferrous Metals and Alloys as now set forth was perhaps too restrictive in that it implied that no assignment in the non-ferrous metals field could be made to committees other than Committee B-2, which, of course, is not the case. The Board accordingly modified the scope of Committee B-2 to read as follows with the elimination of the word "heretofore," which is included below in brackets:

> The formulation of specifications as to composition and performance for all refined non-ferrous, precious and miscellaneous non-ferrous alloys and metals not specifically assigned [heretofore] to some other committee.

This scope may still require some study in order to give a true understanding of the intent.

The Board has taken action to approve revised scopes of other committees, as follows:

The scope of Committee D-16 on Industrial Aromatic Hydrocarbons has been changed to read as follows:

> Nomenclature, specifications, and methods of test of those aromatic and heterocyclic chemicals, generically classed as coal chemicals, whether derived from coal, petroleum, or any other source, by synthesis or physical separation, and used industrially, either alone or as mixtures, as intermediates or solvents.

This broadens the scope to include the phenols and creosols not heretofore included.

In order to bring the title of the committee in line with this enlarged scope, the committee's title has been changed to "Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials."

The scope of Committee D-19 on Industrial Water has been changed from its present form: namely,

> The study and description of industrial water as an engineering material including terminology; methods of sampling, analysis and testing; interpretation of results of analyses and tests; classification; and the preparation of specifications,

to the following:

> The study of water as an engineering material; the standardization of terminology and of methods for sampling, analysis, and corrosivity testing of industrial water, industrial waste water, and water-formed deposits: and the formulation of performance (not purchase) specifications.

The Board has also granted permission to Committee D-19 to "declassify" its membership since it does not seem appropriate to attempt to classify any of the members as "producers" of industrial water.

Study is now being given to the statement of scope of Committee E-5 on Fire Tests of Materials and Construction. The work of this committee ties in with that of several other committees that have been interested in the development of fire tests or flame tests of various materials of construction, and it is desirable that there be a clear understanding of the responsibilities of these several committees and that of Committee E-5.

Agreement has been reached between Committees A-6 on Magnetic Testing and Committee E-7 on Non-Destructive Testing whereby the latter committee will within its present scope assume jurisdiction for methods of magnetic testing that are used strictly as a non-destructive test, as distinct from tests to determine magnetic properties of metals.

In the increasing complexity of the Society's committee work, it has been natural that there is an ever-increasing inter-relation between the work of the committees, and the matter of overlapping jurisdiction and of cooperation is becoming an increasingly important one. This may result in the organization of more coordinating committees.

Fifty-Year Anniversaries:

Two of the technical committees are this year celebrating the fiftieth anniversary of their organization: Committee D-1 on Paint, Varnish, Lacquer, and Related Products in June, and Committee C-1 on Cement in October. Committee A-1 on Steel celebrated its fiftieth anniversary two years ago, the committee having been organized under the American Section of the International Association for Testing Materials prior to the incorporation of ASTM as such.

Emergency Procedure:

Reference was made in the report a year ago to the reinstitution of ASTM emergency procedure. The report of the Administrative Committee on Standards (Appendix II) records actions taken under this procedure.

Inclusion of Safety Hazard Precautions in ASTM Standards:

Consideration was given by the Board during the year to the Society's responsibility in connection with precautionary notes or references to safety and hazard provisions appearing in many ASTM standards. While legal advice indicated that there is no legal responsibility involved on the part of the Society, it was agreed that it would be to the interest of the Society to encourage safety and to make such references in ASTM standards as may be helpful. The following statement recording the policy of the Society in this matter has been placed in the hands of each committee officer:

> Where there are personal hazards in methods of test, a warning should be given to this effect, pointing out briefly where, in the method, these hazards exist, and the protective or precautionary measures to be taken. It should be recommended that operators consult their supervisors or safety personnel for more detailed instructions.
>
> A statement should be included in the methods that where more information is required, inquiry be directed to ASTM Headquarters.

Any request for information would be referred by the Headquarters Staff to the appropriate technical committee.

Proposed Use of Dewey Decimal System in ASTM Standards:

The Board has referred to the Administrative Committees on Standards and Papers and Publications a suggestion from Committee C-16 on Thermal Insulating Materials that consideration be given to the use of the Dewey Decimal System in ASTM standards.

District and Related Activities

The thirteen ASTM Districts functioned smoothly during the year. There were several outstanding meetings, as noted below, with a complete list in the accompanying table. Two of the districts rendered valuable service to the Society: The Philadelphia group for the third consecutive year acted as host for the 1951 Annual Meeting in Atlantic City, planned the ladies' entertainment, sponsored the annual dinner and underwrote the respective costs. The Cleveland District was host at a President's Reception during the Spring Meeting in March, and arranged the dinner program.

The New York District Council was the nucleus for the Committee on General Arrangements for the 50th Anniversary Meeting, which group is doing outstanding work arranging for many of the features for this meeting, June 23–27, 1952.

Several of the district councils are cooperating with the Membership Committee in membership work. Frequently throughout the year, the officers of the Society and the Staff call on council members for assistance in connection with specific projects. The districts and their governing councils have come to occupy an important and helpful place in various phases of the Society's activities.

District Meetings:

It is difficult to single out, for special mention, any of the district meetings. From the standpoint of attendance, however, two were notable: the Detroit Meeting, with its round-table discussion on "Power from the Atom," having an attendance of 900, one of the Society's largest meetings of any kind, and the Southern California meeting in November, 1951, at which the Marburg Lecturer, F. L. LaQue, spoke, with over 500 in attendance.

It will be noted from the accompanying table that President Fuller had a busy year visiting the districts. At all of the meetings where he gave his paper, "Solving Problems in Materials," he was given a warm reception, and his paper was well received. The Northern and Southern California Districts were pleased that the Marburg lecturer, F. L. LaQue, could visit them and give a version of his outstanding lecture.

Several of the district meetings were arranged jointly with local chapters of other societies.

Meetings were held for the first time in Louisville, Ky., Allentown, Pa., and Milwaukee, Wis., with the cooperation of the respective districts, namely, Ohio Valley, Philadelphia, and Chicago. All were well attended and enabled members in these cities to meet each other, the President, and other officers present.

New England continued its policy of having meetings in various cities, and in addition to its home base, Boston, there was a good meeting in Providence, R. I.

National Meetings

The Society's 54th Annual Meeting in Atlantic City, June 18–22, 1951, was another record-breaking one. There was an extensive technical program, including 7 symposiums, there being a total of 23 technical sessions. There were more technical committee meetings than ever before—some 615 throughout the five days of the meeting—and the registered attendance was at a new record of 2277. A detailed account of the meeting appeared in the July, 1951, ASTM BULLETIN. The 1951 *Proceedings* and several special technical publications contain the reports and papers presented.

The 1952 Spring Meeting held in Cleveland on March 5 during ASTM Committee Week included a symposium on "Testing Metal Powders and Metal Powder Products." This symposium will be published during the summer.

During Committee Week, there were some 300 meetings of technical committees, with a total registration for the week of 1224. Several committees had papers sessions, including Committee E-12 on Appearance, which sponsored a Symposium on Color Difference Specifications, Committee D-18 on Soils for Engineering Purposes, which reviewed the use of radioisotopes in soils mechanics and Committee D-1 on Paints, which sponsored a session on printing inks. Notes on these committee sessions appeared in the April ASTM BULLETIN.

Centennial of Engineering:

The Society is participating in the Centennial of Engineering in Chicago in September 1952. One of the sessions on "One Hundred Years of Engineering Progress with Wood" is being sponsored by the ASTM in cooperation with other societies, and the first Gillette Memorial Lecturer Mr. N. L. Mochel, Westinghouse Electric Corp., will present a lecture at another session.

1953 and 1954 Meetings:

The 1953 Annual Meeting will be held at Chalfonte-Haddon Hall, Atlantic City, N. J., June 29–July 3. This was originally scheduled in the previous

ASTM MEETINGS, JUNE 1951–MAY 1952, INCLUSIVE.

Meeting	Place and Date	Notes
Annual Meeting	Atlantic City, N. J. Hotel Chalfonte-Haddon Hall June 18–22, 1951	23 Technical Sessions; 615 Committee Meetings; 55 New Tentatives Approved. (Registered Attendance 2277—375 Ladies)
ASTM Committee Week	Cleveland, Ohio Hotel Statler March 3–7, 1952	300 Committee Meetings (Registered attendance 1224)
Spring Meeting	Cleveland, Ohio Hotel Statler, March 5, 1952	Symposium on Testing Metal Powders and Metal Powder Products President's Reception: "Solving Problems in Materials", by President T. S. Fuller[a]; "Engineering for Radioisotopes," by A. F. Rupp.
District or Local (sponsored by Councils indicated)	Cambridge, Mass. (New England District) Commander Hotel October 9, 1951	"Industrial Applications of Radioactive Methods", by Prof. John W. Irvine, Jr.; "Engineering for Radioisotopes," by A. F. Rupp.
	Louisville, Ky. (Ohio Valley District) University of Louisville October 10, 1951	Jointly with Louisville Section, American Society for Metals. "Solving Problems in Materials, Particularly Metals," by President T. S. Fuller[a]; "Testing Mettle," by Rev. William W. Slider. Plant visits.
	Pittsburgh, Pa. Royal York Apartments October 23, 1951	President's Night; "Solving Problems in Materials," by President T. S. Fuller.[a]
	Buffalo, N. Y. (Western New York-Ontario) Hotel Steraton October 24, 1951	"Solving Materials Problems in the Electrical Manufacturing Industry," by President T. S. Fuller.[a]
	New York, N. Y. Engineering Societies Bldg. October 26, 1951	National President's Night; "Solving Problems in Materials," by President T. S. Fuller.[a]
	San Francisco, Calif. (Northern California) Engineers' Club October 31, 1951	Joint meeting with San Francisco Bay Area Section, National Association of Corrosion Engineers. "Corrosion Testing and Engineering," by F. L. LaQue.[b]
	St. Louis, Mo. Engineers' Club of St. Louis November 1, 1951	Joint meeting with St. Louis Chapter, American Society for Metals and St. Louis Engineers' Club. "High-Temperature Metals," by Dr. Albert E. White.
	Allentown, Pa. (Philadelphia District) Hotel Traylor November 2, 1951	Jointly with Lehigh Valley Chapter, American Society for Metals. "Solving Problems in Materials, Particularly Metals," by President T. S. Fuller[a]; "Just Problems," by A.O. Schaefer.
	Los Angeles, Calif. (Southern California) Rodger Young Auditorium November 8, 1951	Joint meeting with other cooperating Southern California technical groups (ASM, ASCE, ASEE, AICE, ASME, NACE, and AIME). "Corrosion Testing and Engineering," by F. L. LaQue.[b]
	Chicago, Ill. Western Society of Engineers November 19, 1951	Joint meeting with Western Society of Engineers. "Problems in Materials," by President T. S. Fuller.[a]
	Philadelphia, Pa. Drexel Institute of Technology December 18, 1951	Jointly with Metals Division, Phila. Section, The American Society of Mechanical Engineers. "The Production and Application of Titanium," by Dr. E. A. Gee; "The Melting, Forging, and Application of Titanium," by C. I. Bradford.
	Philadelphia, Pa. Phila. Textile Institute February 5, 1952	"Problems Accompanying the Introduction of the Newer Synthetic Fibers," by Dr. John H. Dillon; Coffee talk by Bertrand W. Hayward.
	Lackawanna, N. Y. (Western New York-Ontario) Bethlehem Steel Co. trip February 15, 1952	Plant Visitation, Bethlehem Steel Co., Lackawanna, N. Y.—Hot and Cold Rolling of Steel.
	New York, N. Y. Engineering Societies Bldg. February 29, 1952	Joint meeting with Machine Design Division, American Society of Mechanical Engineers, and New York Section, American Society of Lubricating Engineers. "Factors in Corrosion with Respect to Design and Lubrication Problems," by F. L. LaQue.[b]

ASTM MEETINGS, JUNE 1951–MAY 1952 INCLUSIVE (*Continued*)

Meeting	Place and Date	Notes
	Pittsburgh, Pa. Mellon Institute March 3, 1952	Joint meeting with Pittsburgh Section, American Institute of Mining & Metallurgical Engineers. "Rôle of Boron Steel in the Present Emergency," by Porter R. Wray.
	Milwaukee, Wis. (Chicago District) Engineers' Society of Milwaukee March 12, 1952	Joint meeting with Milwaukee Section, The American Society of Mechanical Engineers. "Solving Problems in Materials," by President T. S. Fuller.[a]
	San Francisco, Calif. (Northern California) Marine Memorial Building March 18, 1952	Jointly with San Francisco Section, American Institute of Electrical Engineers. "Solving Materials Problems in Electrical Manufacturing Industry," by T. S. Fuller[a]; "European Aspects of Standardization and Testing of Materials," by C. L. Warwick.
	Los Angeles, Calif. (Southern California) Rodger Young Auditorium March 21, 1952	Joint meeting with American Institute of Electrical Engineers. "Solving Problems in Materials," by President T. S. Fuller[a]; "European Aspects of Standardization and Testing of Materials," by C. L. Warwick.
	Detroit, Mich. Rackham Memorial Bldg. April 28, 1952	"Power from the Atom"—Panel discussion by Mr. A. W. Hanson, Dow Chemical Co.; Messrs. E. L. Nugent and H. A. Wagner, Detroit Edison Co.; and A. L. Donnell, Vitro Corp. Dinner speaker: President T. S. Fuller.
	Providence, R. I. (New England District) Providence Engineering Society May 14, 1952	"Solving Problems in Materials," by President T. S. Fuller[a]; "Synthetic Rubber," by Dr. John T. Blake.
	Rochester, N. Y. (Western New York-Ontario) Eastman Kodak Co. trip May 16, 1952	Plant Visitation to Eastman Kodak Co., Building 28, Rochester, N. Y.

[a] President Fuller's talk, various versions of which were presented at district meetings, is published in the ASTM BULLETIN, No. 185, October 1952, p. 51 (TP167).

[b] The address by Mr. F. L. LaQue was based on his monumental 1951 Edgar Marburg lecture "Corrosion Testing," published in *Proceedings*, Am. Soc. Testing Mats., Vol. 41, pp. 495–582 (1951); also issued separately.

week, but as a measure of cooperation with the Pan American Railway Congress, it was agreed to shift the meeting to the week beginning June 29.

The 1953 Spring Meeting and Committee Week will be at the Hotel Statler, Detroit, Mich., March 2–6.

Reservations have been made with the Hotel Sherman and other cooperating hotels for the 1954 Annual Meeting and 11th Exhibit of Testing Apparatus and Related Equipment, to be held in Chicago, Ill., the week of June 14–18.

The Spring Meeting and Committee Week in 1954 is scheduled to be held in Washington, D. C., March 1–5.

Centennial of Engineering: The Society is participating in the centennial of engineering to be held in Chicago, Sept. 1952.

Publications

The attached report of the Administrative Committee on Papers and Publications (see Appendix IV) lists the very considerable number of publications that have been issued during the past year. The special publications are assuming an ever increasingly important place in the Society's publication set-up. These for the most part comprise the papers and discussions that are presented as symposiums at the Annual Meeting, but some are in the nature of bibliographies which various technical committees are sponsoring. The very considerable number of symposiums that are being held as a part of this Annual

Meeting will result in a number of new Special Technical Publications (STPs).

The regular publications, of course, are the first consideration, and these comprise the *Proceedings* and the Supplements to the Book of Standards. During the past year these comprised 1332 pages of *Proceedings* and 1916 of Supplements. The Book of Standards is to be re-issued this year in seven parts rather than six; Bible paper is being used so as to cut down shelf space requirements.

Reference is made in the report under Special Publications in Prospect to a Fifty-Year Index of Technical Papers and Reports. This should be a very significant publication. It was intended as a commemorative volume for this Fiftieth Anniversary Year and every effort is being made to have it appear in time for the Annual Meeting. The Staff had the advice of a number of professional librarians in drawing up plans for the Index. In the past, indexes have been issued covering approximately five-year periods up until the year 1940, but no index has been issued since. The present accumulative index should be of considerable service.

H. W. Gillett Memorial Lecture:

While not strictly speaking a publication matter, mention should be made of the establishment of a new lecture, since it will be part of the programs of the annual meetings of the Society. This is a lecture established in cooperation with Battelle Memorial Institute to honor the late Horace W. Gillett, who was an outstanding worker in the engineering application of metals. This lecture will be a companion lecture to the Edgar Marburg Lecture and is being presented for the first time at this Annual Meeting.

Administrative Matters

The Board was called upon during the year to fill a vacancy among its members. This vacancy was created when the Nominating Committee acceded to the request made by Prof. F. E. Richart near the end of his term as Vice-President that, because of health condition, his name be withdrawn from consideration for the office of President, and nominated Mr. T. S. Fuller as President when his term as Vice-President still had a year to run. Under power given it in the By-laws, the Board filled the vacancy by the election of Dr. H. L. Maxwell, Section Supervisor, Mechanical Engineering Consultants, E. I. du Pont de Nemours and Co., Inc., as Vice-President for a term of one year.

Administratively, the Board is faced with the large problem of filling the vacancy created by the death of the Executive Secretary, Mr. Warwick, and a special committee of the Board is now giving consideration to this matter. Until such time as a successor to Mr. Warwick is elected, the Administrative Staff is carrying forward the operations of the Society under the direction of the Assistant Executive Secretary, R. E. Hess, who has been empowered by the Board to exercise the duties, responsibilities, and authority of the Executive Secretary.

Just a week prior to Mr. Warwick's death, Mr. J. K. Rittenhouse retired as Treasurer after 43 years of service with the Society. Upon his retirement the Board elected Mr. Rittenhouse Treasurer Emeritus. In anticipation of his retirement the Board had appointed Mr. R.

J. Painter as Treasurer, Mr. Painter to continue his activities as Assistant Secretary as well. Miss Dorothy P. Douty has been appointed as Assistant Treasurer.

In the Board's report a year ago, mention was made of the desire to secure an assistant in the technical and administrative staff. This post, however, has not as yet been filled. The report also referred to the employment of W. W. Menz as an assistant editor. Mr. Menz has since left the employ of the Society; and while no direct replacement has been made, there has been a realignment in the duties of other members of the editorial staff, and the staff has and is being built up to provide more assistance in the editing of the publications in view of their increasing volume.

Two more members of the staff have completed twenty-five years of service, namely, Mr. Paul J. Smith, Assistant Technical Secretary and Standards Editor, and Miss Florence Artis, Secretary to the Office Manager, making a total of six members of the present active staff who have served 25 years or more. In November of this year Miss Mary E. Dickson, in charge of membership and committee records, will complete her twenty-fifth year of service on the staff.

Society Headquarters:

In view of the continued increase in the Society's activities, which has naturally led to an increase in the Headquarters Staff, the Board wished to be assured of being able to take care of any necessary expansion in headquarters. It accordingly has acquired a property to the rear of the present building which had been in use as a parking lot. The lot is twice the area of the lot occupied by the present headquarters building and extends from Quarry St. to Cherry St. A special committee of the Board is now looking into the matter of expanding the present headquarters and how the new property can be used to the best advantage.

The headquarters have continued to be regularly used by committees and members of the Society. In the calendar year 1951 there were 90 committee meetings and conferences held in the building, including several meetings of other organizations to whom the Society is always pleased to extend this courtesy.

Later in this report is given full information regarding the operation of the Building Fund through which the purchase of the present headquarters was made. The headquarters building is carried on the Balance Sheet as an asset after depreciation of $160,640.87. The building is nearly clear of indebtedness, there being only a note payable to General Funds of $11,600 as of December 31, 1951. Provision is made in the budget under Headquarters Occupancy Expense to pay off this loan at a rate of approximately $1130 a year. To this headquarters account will now need to be added the purchase cost of the additional property, $29,178.61, which has been financed through a further loan from the General Funds.

The cost of operating the headquarters building in 1951, including full depreciation charges and portions of staff salaries chargeable to management maintenance services, was about $2.10 per sq. ft.

Membership

On June 1, 1952, the membership of the Society totaled 7250, compared with a total of 7001 one year ago. Gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1951	June 1, 1952	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	22	22	...	...	5	...	4	1	5	5	...
Perpetuity and Life	11	11	...	...	...	...	...	...	...	...	...
Sustaining	236	255	...	...	...	3	22	...	3	22	19
Company, Firm, etc.	1704	1745	41	14	...	29	19	106	84	125	41
Individual, etc.	4918	5111	162	91	44	21	24	487	318	511	193
Junior	110	106	12	9	...	16	...	33	37	33	4[a]
Total	7001	7250	215	114	49	69	69	627	447	696	249
Student	458	398	21	246		19		226	286	226	60[a]

[a] Net Loss.

It will be noted that 627 new members were elected, compared with 652 for the preceding year. However, the fewer losses from resignations, delinquencies and death, 378 this year compared with 412 the previous year, brings the net increase to 249, compared with the net increase reported a year ago of 240. It will be seen from the table that there was a substantial increase in the number of sustaining, company, and individual memberships. The growth of the sustaining membership class is encouraging. In the past two years it has risen from 214 to the current figure of 255; and company memberships in this same period increased from 1658 to 1745. These classes particularly are important in insuring sound financial support of the Society's technical operations.

Considering that our membership is now just 7250, it is interesting to compare this with the figures for ten and twenty years ago: in 1942 our total membership was 4640, and in 1932 it was 4163. A true comparison would, of course, need to consider the relative percentages of sustaining, company, and individual memberships. Nevertheless the steady growth in the total membership is encouraging.

Sustaining Members:

There have been twenty-two new sustaining members, and there were three losses, being transfers to company membership. The new sustaining members are:

Aluminum Laboratories, Ltd.
American Brake Shoe Co.
Baldwin-Lima-Hamilton Corp.
Baltimore and Ohio Railroad Co.
Brooklyn Union Gas Co.
Certain-teed Products Corp.
Columbia-Geneva Steel Division, United States Steel Co.
Granite City Steel Co.
Illinois Central Railroad Co.
Mutual Chemical Company of America
Newport News Shipbuilding and Dry Dock Co.
Norfolk and Western Railway Co.
Northern States Power Co.
Quaker State Oil Refining Corp.
Radio-Television Manufacturers Assn.
Reynolds Metals Co.
Rome Cable Corp.
Schenley Distillers, Inc.
Sinclair Refining Co.
Swift and Co.
Henry Vogt Machine Co.
West Penn Power Co.

Several other companies have signified their intention of becoming sustaining members.

50-Year Members:

There are ten individuals and companies as noted below that have been connected with the Society continuously for 50 years, having joined in 1902, the year of incorporation:

Charles Derleth, Jr.
William C. Du Comb

Bradley Stoughton
Ajax Metal Division of H. Kramer and Co.
E. L. Conwell and Co.
International Harvester Co.
Jones & Laughlin Steel Corp.
Lukens Steel Co.
The Sherwin-Williams Co.
Standard Steel Works Division, Baldwin-Lima-Hamilton Corp.

These members will be recognized at the Fiftieth Anniversary meeting.

40-Year Members:

There is a total of 31 members who this year have completed forty years of membership, which brings the total number of certificates issued to the "Forty-Year Club" to 215. The members who will receive the 40-Year Certificates at this annual meeting are as follows:

Allegheny Ludlum Steel Corp.
Associated Factory Mutual Fire Insurance Cos.
James Aston
Birdsboro Steel Foundry and Machine Co.
Calumet Steel Div., Borg-Warner Corp.
D. J. Demorest
The B. F. Goodrich Co.
Henry R. Gundlach
Kansas State College of Agriculture and Applied Science Library
Kelley Island Lime and Transport Co.
J. B. Kommers
Laclede Steel Co.
Lloyd's Register of Shipping
John R. MacGregor
Kenneth Gerard Mackenzie
Ibrahim F. Morrison
National Lime Assn.
New Jersey State Highway Dept.
Niagara Mohawk Power Corp.
Ohio State University Library
Owen K. Parmiter
Patent Office Library (London)
Pioneer Service and Engineering Co.
F. B. Porter
Raybestos-Manhattan, Inc., Manhattan Rubber Div.
F. W. Smither
John F. Tinsley
Travelers Insurance Cos.
Union Steel Castings Div., Blaw-Knox Co.
Warner Co.
University of Wisconsin Library

Deaths:

The Society has lost the following 49 members through death:[1]

Angus, W. F. (1904)[a]
Bales, C. E. (1926)
Berger, E. H. (1934)
Bregman, Adolph (1951)
Campbell, John T. (1924)
Clay, Wharton (1942)
Edwards, Llewellyn E. (1912)
Fielding, Harold (1948)
Findley, J. K. (1943)
Fulton, C. E. (1945)
Fyke, F. C. (1946)
Griffiths, Frederick J. (1915)
Grove, H. A. (1950)
Hargan, J. A. (1950)
*Hatt, William K. (1898)
Haydock, Charles (1927)
Haynes, Hilliard G. (1946)
Hettinger, E. L. (1920)
Hirschtal, Meyer (1951)
Hylton, W. Harold (1947)
*Job, Robert (1900)
Kehl, Robert Joseph (1919)
Knappen, Theodore T. (1944)
Lindsay, G. L. (1929)
McCreery, Don Hull (1946)
McInnis, John J. (1936)
McKnight, William A. (1945)
Moreland, Edward L. (1925)
Paquin, Felix (1926)
Pelly, John F. (1947)
Pelton, B. W. (1947)
Reilly, P. C. (1916)
*Richart, Frank E. (1918)
Roos, P. K. (1948)
Ryan, Victor A. (1951)
Saunders, Harold F. (1945)
*Smith, H. E. (1902)
Smith, Roy M. (1951)
Staley, Howard R. (1938)
Sterling, Calvin (1951)
Sullivan, William L. (1948)
Turneaure, F. E. (1902)
Van Kleeck, Arthur (1948)
*Vassar, Hervey S. (1915)
Walker, Percy H. (1907)
Ware, E. E. (1912)
Warwick, C. Laurence (1912)
Willis, E. A. (1935)
Wolter, William J. (1944)

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[1] Since the preparation of this report, advice has been received of the death of Marcus A. Grossmann and R. L. Hallett.

[a] Date of Membership.

* Honorary Member.

In addition to the above, the following representatives of company members of the Society passed away:

L. Dudley Coles, City of Newark, Dept. of Public Works
William T. Donahue, Onyx Oil and Chem Co.
J. F. Garneau, Mica Fabricators Assn.
H. G. Hill, Ehret Magnesia Manufacturing Co.
P. L. Irwin, Baldwin-Lima Locomotive Co.
W. J. Johnston, Coplay Cement Mfg. Co.
C. E. MacQuigg, Ohio State University Engineering Experiment Station
D. W. McNaugher, Jr., Robert W. Hunt Co.
Alan Morris, Bridgeport Brass Co.
W. H. Patterson, Thomas A. Edison Storage Battery Div.
C. A. Whitton, Oakland Public Schools
C. S. Wicker, Buffalo Slag Co.
Theodore Zuschlag, Magnetic Analysis Corp.

This has been a year of heavy losses among active members and officers of the Society. Earlier in this report mention is made of death of the Society's long-time administrative head, Executive Secretary C. Laurence Warwick. In addition there were five men whose notable work and meritorious service had been recognized through election to Honorary Membership in the Society, namely, William K. Hatt, Robert Job, Frank E. Richart, H. E. Smith, and Hervey S. Vassar. All five had served as members of the Board of Directors; Mr. Vassar was a Past-President, and Professor Richart had served as Vice-President, 1949–1951. Messrs. F. E. Turneaure and P. H. Walker also had served on the Board of Directors, and Mr. Walker was among the first group of ASTM members receiving Awards of Merit in 1950.

In the death of Professor Hatt the Society loses one of its two individual members who have been affiliated continuously since 1898, and in the passing of Mr. Job one of two individuals affiliated since 1900. Messrs. H. E. Smith and Turneaure would have been in the "Fifty-Year" group this year; W. F. Angus had been affiliated 48 years, Mr. Walker 45 years, and three of the men, Messrs. Edwards, Ware, and Warwick, had just completed 40 years of continuous affiliation.

Because of the many contributions of these long-time members and officers it is difficult to enumerate them. Mr. Job had done important pioneering technical work, particularly in the early years, in the metals committees. Among Professor Hatt's many contributions was service as Secretary of Committee D-7 on Wood for many years. Professor Richart was an outstanding leader in the fields of cement and reinforced concrete, being active in Committees C-1 and C-9. He was Chairman of C-9, 1944–1946, and had been named an honorary member of that group in 1950. Mr. Vassar did outstanding work in Committees D-9 on Electrical Insulating Materials and D-11 on Rubber and Rubber-Like Materials. H. E. Smith is an outstanding example of a beloved individual whose full life had been wrapped up in ASTM. While his principal work was in Committees A-5 on Corrosion of Iron and Steel and D-1 on Paint, Varnish, Lacquer, and Related Products, of which he was long-time chairman, his other services were many and varied. Mr. Walker's notable work was in Committee D-1 which he headed for a number of years.

A number of the other men have been affiliated with the Society for many years and rendered outstanding services, particularly through work on the technical committees. C. E. Bales made important contributions to the work of Committee C-8 on Refractories, and E. H. Berger had been a mainstay of Committee D-8 on Bituminous Waterproofing and Roofing Materials, of which he was Vice-Chairman. F. C. Fyke was actively concerned with the Steel Committee and other allied groups. E. L. Hettinger, an authority on glass, had participated actively in some of the Society's earlier Photographic Exhibits. G. L. Lindsay was active for many years in Committee C-1 on Cement. E. E. Ware had been a long-time participant in Committee D-1 on Paint, in which field he was an authority. E. A. Willis was concerned particularly with soils and had been awarded the Dudley Medal for one of his technical papers.

Concerning those men who represented their companies and institutions in the Society, exercising the responsibilities for membership, Paul L. Irwin, of the Baldwin-Lima-Hamilton Corp., had been very active in the work of Committee A-1 on Steel. C. E. MacQuigg for years served actively on the Joint Committee on Effect of Temperature on the Properties of Metals, also was active in the Ohio Valley District, staging one of that group's most successful meetings in Columbus last year. Alan Morris was a technical leader in Committees B-3 on Corrosion of Non-Ferrous Metals and Alloys and B-5 on Copper and Copper Alloys. Theodore Zuschlag's contributions were concentrated in Committee A-6 on Magnetic Properties which group had his consistent support for many years. He also had prepared various technical papers.

More complete notes on the contributions of many of these men have appeared in the ASTM BULLETIN, and with these brief notes the Society records its deep appreciation for these contributions and the spirit which motivated them.

Honors and Awards

In line with recently established practice, the Board has continued recognition for outstanding service through the selection of members to receive the Award of Merit. Various awards and medals are also given to recognize outstanding papers and to foster research in certain special fields.

Award of Merit:

The Award of Merit Committee for 1952, comprising L. J. Trostel, chairman, C. H. Fellows, H. M. Hancock, Dean Harvey, and W. A. Zinzow, reviewed numerous suggestions and citations from various technical committees and nominated ten members who by unanimous action of the Board were voted the 1952 Awards of Merit. Each one has contributed in an important way to the work of the Society. Award of Merit certificates will be presented during this annual meeting to the following:

W. P. Davey
G. H. Harnden
J. C. Harris
J. J. Kanter
H. S. Mattimore
D. E. Parsons
H. M. Robinson
J. D. Sullivan
Ray Thomas
F. D. Tuemmler

Recognition of Technical Papers:

The following awards will be made at this annual meeting in recognition of outstanding technical papers:

Charles B. Dudley Medal—presented for a paper of outstanding merit constituting an original contribution on research in engineering materials. The medal this year will be presented to Norman W. McLeod, Engineering Consultant, Department of Transport, Ottawa, Canada, for his paper on "Application of Triaxial Testing to the Design of Bituminous Pavements."

Richard L. Templin Award—presented for a paper describing new testing methods and apparatus, the purpose of the award being to stimulate research in the development of testing methods and apparatus. This year the award will be made to Thomas J. Dolan, Research Professor of Theoretical and Applied Mechanics, University of Illinois, for his paper entitled "Electrically Excited Resonant-Type Fatigue Testing Equipment."

Sanford E. Thompson Award.—presented by Committee C-9 on Concrete and Concrete Aggregates for a paper of outstanding merit in the field of concrete and concrete aggregates. The award this year will be made to H. F. Gonnerman and William Lerch of the Portland Cement Association for their paper entitled "Changes in Characteristics of Portland Cement as Exhibited by Laboratory Tests Over the Period 1904 to 1950."

Reference was made in the report a year ago to the award of the Harold Dewitt Smith Memorial Medal to be made at the October, 1951, meeting of Committee D-13 on Textile Materials to Prof. Edward R. Schwarz of Massachusetts Institute of Technology in recognition of his work in the science of utilization of textile fibers. A second award of this medal was presented at the March, 1952, meeting of Committee D-13 to Dr. Frederic Bonnet, American Viscose Corporation.

The Committee on Sam Tour Award recommended that no award be made this year because in the opinion of the committee no paper submitted during 1951 was considered suitable to receive the award. The purpose of this award is to encourage research on the improvement and evaluation of corrosion testing methods and to stimulate the preparation of technical papers in this field.

Finances

Report for the Fiscal Year of 1951:

The annual statement of the finances of the Society is presented in the form of the report of the auditors for the fiscal year January 1 to December 31, 1951, which appears in Appendix I. The report gives the balance sheet of assets and liabilities, including general funds, building fund, and other special and designated funds; a statement of receipts and disbursements classified into "operating"; (budgeted) and "non-operating"; details of the building fund and of special funds; and investments of Society funds.

Operating Receipts.—Total operating receipts were $613,307.21, the largest in the Society's history. Of this amount receipts from dues and entrance fees were $215,023.75 or 35.1 per cent; receipts from sales of publications were $340,604.88, or 55.5 per cent: and receipts from miscellaneous sources consisting principally of advertising, income from investments, and registration fees total $57,678.58 or 9.4 per cent. Receipts from publication sales topped all previous records, which of course is to be expected with the ever-growing activities of the Society.

In reviewing income from sales of publications, it is desirable to keep in mind that in a sense the Society's operations are on a three-year basis, and thus the year immediately following the issuance of the Book of Standards normally results in higher income. However, sales of the 1949 Book of Standards showed a sustained demand for this publication in its second year (1951), and the sales of special compilations and technical publications (STP's) and separate standards indicate the very favorable reception accorded these various books. It will be seen that income from dues, 35.1 per cent, together with sales of publications, 55.5 per cent, aggregated more than 90 per cent of our income. Years ago income from dues frequently was more than 50 per cent of income, whereas now the situation is reversed and the receipts from the sale of publications, in particular those involving standards, are assuming a very important place in supporting the Society's activities.

In passing it is of interest to note that in 1941 the Society's income was $199,500 and in 1931 it was $140,630.

Operating Disbursements:

With the Society's work expanding continually and publication and other costs increasing considerably, it is not surprising that the operating disbursements for 1951 were considerably higher than previously, totaling $584,199.35. Publication costs, exclusive of overhead, labor, etc., total $246,291.01, including $40,000 applied to the reserve for the 1952 Book of Standards. A growing Staff necessary to carry on the many phases of the work at Headquarters, and even then hard put at times to keep apace with them, plus salary advancements, accounted for 35.5 per cent of the disbursements. This compares with an average ratio of the five preceding years of 34.7 per cent. Thus publication and salary expenditures account for about 78 per cent of the total.

Reference might be made to the considerably higher general office expense totaling $59,867.75. The cost of handling publications has gone up sharply, largely because of increased postage and expressage, and procurement of a considerable stock of stationery, billing forms, and such items sent this portion considerably over the budget. Miscellaneous expenditures include the cost of new billing machines procured after considerable study, further to mechanize our operations.

The Society's contribution to the Retirement Plan for ASTM Employees was $17,289, about 3 per cent of total disbursements, and about 8.3 per cent of the salary roll; it includes for the first time the Social Security Tax totaling $2054.

Summary of 1951 Operations:

Comparing operating receipts with disbursements, there is a favorable balance of $29,107.86. This was encouraging since a normal second year after publication of the Book of Standards might result in a deficit and actually budget operations must be based on the possibility of such a situation.

Balance Sheet.—The appended auditors' report includes a balance sheet of assets and liabilities. Assets in the General Funds total $524,490.65 compared to $439,271.50 a year ago. Total assets including the Building Fund and Special and Designated Funds are $947,676.30 compared to $766,481.06 a year ago. This increase in assets reflects substantial increase in cash and investments in the General Funds, the increased asset represented by the acquisition of the Cherry Street property,[2] and a further substantial increase in Committee Funds—especially in the accounts of the X-Ray Diffraction Committee and the Advisory Committee on Corrosion.

It should be pointed out that in the Balance Sheet no account has been taken of the assets of the Society in the form of publications in stock. This is consistent with many years practice in this respect and, of course, results in a more conservative statement. An inventory of the principal technical publications as of May 1, 1952 is summarized below.

Proceedings (All back copies not incl. 1951)	2 343
1949 Book of ASTM Standards:	
Part 1	14
Part 2	173
Part 3	615
Part 4	1 003
Part 5	1 094
Part 6	1 017

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[2] Attention should be called to the fact that whereas the Balance Sheets for both General Funds and Building Fund are correct in themselves, adding the two together in the consolidated statement brings about a duplication of the value of the Cherry Street property, inasmuch as the money for purchase of the property was loaned (not given) to the Building Fund and hence still appears as an asset in General Funds in the form of a note, whereas the property purchased with that money also appears as an asset in the Building Fund. Therefore, the total assets of the Society considered by themselves are some $29,000 less than the total reported.

1950 Supplements to Book of Standards:	
Part 1	785
Part 2	972
Part 3	1 324
Part 4	1 452
Part 5	1 185
Part 6	1 235
1951 Supplements to Book of Standards:	
Part 1	1 675
Part 2	1 163
Part 3	935
Part 4	1 720
Part 5	1 413
Part 6	1 151
ASTM Methods of Chemical Analysis	3 959
Special Compilations of Standards	18 653
Selected Standards for Students	24 929
Symposiums and Special Reprints	103 509
Reprints of Standards (Approx.)	180 000
Index to ASTM Standards (1951)	7 511
Radiographic Standards for Steel Castings	36

The surplus in General Funds is $259,063.13 which compares with $251,477.84 a year ago or an increase of $7585.29. It should be explained that during 1951 the sum of $25,000 was transferred from the December 31, 1950, surplus into a Reserve Account for additional cost of replacement of the headquarters building, so that in effect the financial operations of 1951 really added $32,585.29 to surplus.

ASTM Building Fund.—The auditors report contains a statement of receipts and disbursements and the Balance Sheet for the ASTM Building Fund. The Building Fund received from General Funds the sum of $1630.89 to cover payment of $497.55 interest and $1133.34 towards retirement of the 1946 loan of $17,000. The Fund also received $5700 for depreciation account which was paid in monthly instalments and invested in shares of Commonwealth Investment Co., a Mutual Fund, under the dividend reinvestment plan by which all dividends are automatically invested in stock at the net asset value. Finally the Building Fund also borrowed from the General Funds the sum of $29,178.61 for the purchase of the Cherry Street property, giving a note bearing interest at 3 per cent so that this amount appears under both receipts and disbursements.

The Balance Sheet is set up to show as assets the complete purchase price of the headquarters building and construction costs from the beginning (depreciated in accordance with the agreed-upon schedule) and all contributions to the Fund as a liability. The reserve for depreciation, $25,750, added to the Building Fund from General Funds for the past five years, appears in the Balance Sheet as a deduction from the construction costs. Thus, the Society's headquarters, including the cost of land, represents an asset on the depreciated basis of $160,640.87. The Balance Sheet now includes also the value of the Cherry Street property as an asset and the aforementioned loan as a liability under "Notes Payable."

The 1946 note of $17,000 bearing interest at 4 per cent has been reduced to $11,600; adding to this the 1951 note of $29,178.61 at 3 per cent gives the total of notes payable reported at $40,778.61.

Investments.—Investments of Society funds (General, Building, Research, Committee, Medal and Lecture Funds) as of December 27, 1951, are given in the appended auditors' report, both book and market values being shown. As of that date the book value of all investments was $361,915.06, compared with $311,843.07 a year ago; the market value of all investments on December 31, 1951 was $374,913.71, about 3.6 per cent more than book value.

It will be recalled that in 1950 because of strong inflationary trends and the obvious desirability of having a larger portion of the Society's holdings in equities in relation to holdings with fixed income securities, substantial sums were invested in Mutual Funds and this was continued during 1951. This has had the effect not only of much wider diversified holdings, but has had a marked effect on the income from dividends and capital gains. A year ago about 41 per cent of investments were in common stocks, whereas on December 31, 1951, the figure was about 54 per cent. Percentage in preferred stocks was the same—13 per cent—but there was a drop of from 46 to 33 per cent in the holdings of bonds.

To provide further diversification, and at the same time take advantage of higher interest rates, the Finance Committee has decided to deposit a portion of the Society's cash, especially committee funds, in several Federal Savings and Loan Associations, all of which have the deposits insured in the Federal Savings and Loan Insurance Corporation up to $10,000 for each account.

The following changes during the calendar year 1951 in the investment portfolio are noted:

GENERAL FUNDS

Sold	*Received*
$27 000 U. S. Treasury Bonds, 1952–54	$27 194.06
2 000 U. S. Treasury Bonds, 1964–69	2 021.25
1 000 U. S. Treasury Bonds, 1967–72	1 006.57
3 800 U. S. Treasury Bonds, 1967–72	3 941.31
2 000 Hudson Coal Co. Bonds	1 996.87
100 sh. Murray Corp. Pfd.	4 474.54
25 sh. Colgate Palmolive Peet Pfd	2 373.02
50 sh. Servel, Inc. Pfd	4 446.10
	$47 453.72

Bought	*Cost*
$20 000 Federal Intermediate Credit Bank Debentures	$20 000.00
45 sh. American Airlines, Pfd	3 667.55
50 sh. Food Machinery & Chem. Pfd	4 750.10
50 sh. Chicago, Rock Island and Pacific Pfd	4 434.60
5 sh. Delaware Power & Light Co	100.00
33 sh. Philadelphia Electric Co	833.25
9 sh. Public Service Elec. & Gas Co	189.00
10 sh. United Gas Improvement Co	252.50
50 sh. American Cyanamid Co	3 669.14
50 sh. Aluminum Co. of America	3 679.74
50 sh. Republic Steel Corp	2 152.93
100 sh. Socony Vacuum Oil Co	2 510.28
50 sh. Dow Chemical Co.	3 944.32
25 sh. American Tel. & Tel	3 798.72
100 sh. Baldwin Securities Corp. (dividend)	400.00
1128 sh. Eaton & Howard Balanced Funds	33 997.92
14 sh. Fundamental Investors, Inc. (dividend)	249.76
7 sh. Broad Street Investing Corp. (dividend)	128.52
19 sh. Eaton & Howard Balanced Funds (dividend)	539.41
5 sh. Carpenter Steel (dividend)	266.25
	$89 563.99

RESEARCH FUND

Sold	*Received*
$2000 Hudson Coal Co. Bonds	$ 1 999.90
30 sh. Butler Bros. Cum. Pfd	2 446.04
5 sh. Delaware Power & Light Co	100.00
33 sh. Philadelphia Electric Co	833.25
9 sh. Public Service Elec. & Gas Co.	189.00
10 sh. United Gas Improvement Co	252.50
	$ 5 820.69

Bought	*Cost*
280 sh. Broad Street Investing Corp.	$ 5 636.40
100 sh. Jones & Laughlin Steel Corp	2 636.06
	$ 8 272.46

TEMPLIN FUND

Sold	*Received*
$1000 U. S. Treasury Bonds 1967–72	$ 1 006.56
Bought	***Cost***
33 sh. Eaton & Howard Balanced Fund	$ 994.62

TOUR FUND

Sold	*Received*
$1500 U. S. Savings Bonds Series G	$ 1 422.00
Bought	***Cost***
50 sh. Eaton & Howard Balanced Fund	$ 1 507.00

BUILDING FUND

Bought	*Cost*
846.473 sh. Commonwealth Investment Co.	$ 6 196.69

1952 Budget:

In the budget for 1952, current income has been placed at $583,500, made up of dues and entrance fees of $220,000; publication sales, $290,000; miscellaneous items, $73,500.

Estimated disbursements are $629,000, made up of publication costs of $247,000; salaries (including Staff expansion and increases in salaries appropriate to meet current conditions), $224,000; and general office expenses, meetings and committees, headquarters, retirement and miscellaneous, totaling $158,000. The budget for publications makes allowance for increases in cost of paper and printing. As mentioned elsewhere, intensive work is under way in preparing for publication of the 50-Year Index to Technical Papers. The cost of issuing this has been estimated at about $7500, and to finance it money will be borrowed from the publication reserve.

Comparing the 1952 estimated income $583,500 and the anticipated expenditures of $629,000, a deficit of $45,500 is noted. In these uncertain times no one can forecast with any degree of certainty, but the budget is based on the premise of estimating receipts on the low side and disbursements on the high side. However, the Finance Committee believes this 1952 Budget is a conservative one. If the deficit develops and totals as much as budgeted, it will be met by using funds from publication and other reserves and from general surplus.

To complete reference to 1952 finances thus far this year, it is noted that during the first five months the following sales and purchases of securities have taken place:

GENERAL FUNDS

Sold	*Received*
$8000 Federal Intermediate Credit	$20 000.00
50 sh. Dow Chemical (rights)	22.71
100 sh. Baldwin Securities	388.84
45 sh. Philco pfd	3 748.52
100 sh. Baldwin Locomotive	1 043.51
100 sh. Lone Star Cement	2 472.60
100 sh. International Harvester	3 275.62
	$ 30 951.80

Bought	*Cost*
Commonwealth Investment	$ 61.74
60 sh. Jones & Laughlin	5 386.73
26 sh. Fundamental Investment Co. (dividend)	503.62
9 sh. Broad Street Investing Co. (dividend)	191.97
49 sh. Eaton Howard Balanced Fund (dividend)	1 497.44
	$ 7 640.60

RESEARCH FUNDS

Sold	*Received*
12 sh. Consolidated Edison	$ 1 279.12
29 sh. Consumer Power	2 970.18
20 sh. Philco	1 667.70
	$ 5 917.00

Bought	*Cost*
50 sh. Eaton Howard Balanced Fund	$ 1 692.50
127 sh. Eaton Howard Balanced Fund	4 224.02
9 sh. Broad Street Investing Co. (dividend)	191.97
163 sh. Commonwealth Investment	5 393.67
	$11 502.16

TEMPLIN FUND

Bought	*Cost*
1 sh. Eaton Howard Balanced Fund (dividend)	$ 30.56

TOUR FUND

Bought	*Cost*
1 sh. Eaton Howard Balanced Fund (dividend)	$ 30.56

BUILDING FUND

Bought	*Cost*
432.10 sh. Commonwealth Investment	$ 3 166.27

The total book value of Society investments as of May 31, 1952, in all funds was $344,053.01, divided approximately into 30 per cent in bonds, 13 per cent in preferred stocks, and 57 per cent in common stocks. The Society's cash balance in General Funds as of the same date was $400,584.57.

Retirement Plan

Last year's report showed there were 29 participants in the ASTM Retirement Plan. In November of 1951 one new participant was added, and since that time the number has been decreased by three due to the retirement of Messrs. J. K. Rittenhouse and R. W. Parks, and the death of Mr. Warwick. No new participants came into the Plan during 1952; and the total number of participants as of May 3, 1952, is 27.

Nine additional policies were taken out on present participants, the employes contributing $138.20 of the annual premiums and the Society $1471.21. The amount of $16,700 was budgeted for the Society's contributions to the Retirement Fund for 1952, which is sufficient to meet the Society's obligations. The Society's contribution will now be reduced for 1952 by two-thirds of the annual premium on Mr. Warwick's policies; and the recaptured share of the Society's equity in Mr. Warwick's "unmatched" policies will be placed in the Retirement Fund Reserve.

Developmental Activities

Much of the work of the Society can be considered broadly as representing developmental activities, as, for example, some of the work carried on by district councils, technical committees, etc., quite apart from the general effort that is made to see that the work of the technical committees is made use of to the greatest extent possible. The Board wishes to have a continuing study of and perhaps augment the work that is now being done and is organizing a new administrative committee, having in mind development in an even broader sense. This administrative committee is to be designated Administrative Committee on Member, Industry and Public Relations. The following have accepted membership on the committee:

A. G. Ashcroft, *Chairman*, Alexander Smith, Inc., White Plains, N. Y.
A. R. Ellis, Pittsburgh Testing Laboratory, Pittsburgh, Pa.
J. B. Hunter, N. W. Ayer & Son, Inc., New York, N. Y.
G. E. Hopkins, The Wool Bureau, New York, N. Y.
D. S. MacBride, Hercules Cement Corp., Philadelphia, Pa.
R. A. Schatzel, Rome Cable Corp., Rome, N. Y.
J. R. Townsend, Bell Telephone Laboratories, Inc., Murray Hill, N. J.
Chairman of The Board of Directors' Committee on Developmental Activities, *Ex-officio*.

Cooperative Activities

Many of the cooperative activities with other organizations are carried out as a regular procedure and require no special comment here. Mention is made of only a few matters under this category, including certain new developments.

Of special note is an arrangement that has been set up with the Office of Defense Mobilization (ODM) under which the Society has entered into a contract to supply assistance to the ODM in matters concerning conservation of materials. A staff engineer has been engaged for the specific purpose of working with Mr. J. R. Townsend, who is Consultant to the Director of ODM on Materials Conservation. The ASTM assists in organizing conferences to consider ways and means of conserving materials in cases of extreme shortages. So far a conference has been held on the subject of nickel, and similar conferences are being called with respect to cobalt and structural steel for buildings, having in mind especially fabrication by welding.

Committees of the Society continue to review Federal materials specifications in draft form, comments and recommendations being forwarded to the Federal Specifications Board for its consideration. Contacts between FSB and ASTM work at the staff level have been maintained. This review has also extended to the standards of various foreign countries, having in mind that exchange of views at this level will expedite more formal discussions carried out under the auspices of the International Organization for Standardization (ISO). The Executive Secretary on his trip to Europe last fall found considerable interest in this on the part of various standardizing agencies abroad. His trip did much to cement the cordial relations existing between the ASTM and these organizations. Cooperation with the British Institution of Petroleum in the development of oil measurement tables is nearing completion and it is expected the tables will be published within the next few months.

The Board approved the establishment of a Joint Committee of Committee D-10 on Shipping Containers and the American Association of the Pulp and Paper Industry, to coordinate work of the two groups in the field of containers. In order to set up the proper machinery for prompt endorsement of tentatives and standards prepared by Committee B-8 on Electrodeposited Metallic Coatings, a Joint Committee of B-8 and the American Electroplaters Society has also been approved by the Board.

The Board has accepted an invitation from the Welding Research Council, Engineering Foundation, for the Society to join in the sponsorship of the Council.

Following are certain appointments on cooperative activities made during the year:

Fred Burggraf has been appointed as

the Society's representative on the American Documentation Institute, succeeding R. W. Crum, deceased.

W. S. Housel has been appointed as an alternate on the Highway Research Board of the National Research Council, succeeding F. E. Richart, deceased.

F. E. Clarke and Roy F. Weston have been appointed as Society's representatives on the Standard Methods Committee of the American Public Health Association.

American Standards Association:

The Society's technical relationships with the work of the American Standards Association come directly under the responsibility of the Administrative Committee on Standards, and the report of that committee (Appendix II) discusses a number of matters that have developed during the year, including submittal of ASTM Standards to the ASA for approval as American Standard.

Mr. J. R. Townsend was re-appointed as the Society's representative on the ASA Standards Council for the ensuing three years. In response to an invitation from the ASA for the Society to nominate a member of the ASA Board of Directors to serve for three years, R. D. Bonney was nominated and has been elected as a Director of ASA.

The following appointments have been made on certain of the Correlating Committees of ASA: Myron Park Davis on Safety Code Correlating Committee (reappointed), M. N. Clair on the Building Code and Construction Standards Correlating Committee (reappointed), H. J. Ball on the Consumer Goods Committee, succeeding A. G. Ashcroft, and L. B. Jones on the Mechanical Standards Committee, succeeding J. R. Townsend.

International Activities:

The principal contacts of the Society with international activities during the past year have been in connection with various standardization projects being undertaken in the International Organization for Standardization (ISO). The status of a number of these projects is set forth in the report of the Administrative Committee on Standards (Appendix II). Reference was made in the report a year ago to the fact that America is handling the secretariat of some of the ISO projects, and ASTM is interested in a number of these wherever materials are concerned. In addition to the secretariats referred to a year ago, Committee E-1 on Methods of Testing is now considering heading up the group responsible to the ASA for the secretariat of the Committee on Viscosity. The secretariat of ISO Committee 26 on Copper and Copper Alloys is still under development, ASTM Committee B-5 on Copper and Copper Alloys, Cast and Wrought having an important interest in this work.

The Society will be represented at meetings of several subcommittees of ISO Committee 38 on Textiles being held in New York during the week of June 9, at the meeting of ISO Committee 56 on Mica during the same week, and will have individuals present as observers at meetings of ISO Committee 17 on Iron and Steel. Discussions at the latter meeting are being confined to methods of testing. A meeting of ISO Committee 50 on Lac is being held in New York during the following week, and Subcommittee XIII of Committee D-1 on Paint, Varnish, Lacquer, and Related Materials is organizing the delegation that will participate in these meetings.

During the year, nine teams sponsored by the Mutual Security Agency (formerly the Economic Cooperation Administration) have visited ASTM headquarters for discussion of Society's work in the materials field, including such matters as standard tests and specifications, and conservation of critical materials.

The Society has received many letters of appreciation from the MSA and others on the value of the various conferences that were held.

During Mr. Warwick's European trip he met with many observations with respect to re-instituting in some form the International Association for Testing Materials, or at least the arrangement of international conferences on materials. The Fiftieth Anniversary Meeting of ASTM will be attended by a number of visitors from abroad and will partake partly of such an international conference on materials.

Respectfully submitted on behalf of the Board of Directors.

T. S. FULLER,
President.

R. E. HESS,
Asst. Executive Secretary.

June, 1952.

APPENDIX I

REPORT OF THE AUDITORS FOR THE FISCAL YEAR JANUARY 1 TO DECEMBER 31, 1951

Philadelphia, January 9, 1952

MR. C. L. WARWICK, *Executive Secretary*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pennsylvania

Dear Sir:

We have examined the books and accounts of the American Society for Testing Materials for the year ended December 31, 1951. We did not make a detailed audit of all transactions, but made tests to the extent we considered appropriate in determining the accuracy of the accounts.

Accounts receivable were not verified by correspondence with debtors. The investments owned by the Society, were examined by us; all income from investments for the period under review was properly accounted for.

We have prepared and submit, herewith, balance sheet as of December 31, 1951, statement of cash receipts and disbursements for the year ended that date, and other supporting schedules which, in our opinion, subject to the foregoing comment, present fairly the financial position of the Society at December 31, 1951, and the results of its operations for the year ended that date.

Respectfully submitted,

JOHN HEINS & CO.

BALANCE SHEET AS OF DECEMBER 31, 1951

(Including Special and Designated Funds)

ASSETS

General Funds:			
Cash	$205 597.75		
Less Check No. 4634 as of December 12, 1951 (drawn against cost of 1951 *Proceedings* and 1951 Supplements to 1949 Book of Standards)	41 100.00		
	164 497.75		
Investments (Market Value $276 727.69)—Cost	263 995.13		
Accounts Receivable	35 960.55		
Notes Receivable (Building Fund)	40 778.61		
Advance to Forrest Products Laboratory	500.00		
Total Current Assets General Funds		$505 732.04	
Furniture and Fixtures (depreciated book value)		18 758.61	
Total Assets General Funds			$524 490.65
Building Fund:			
Cash		1 572.28	
Investments (Market Value $25 531.93)—Cost		26 479.52	
Land (Cost)		30 000.00	
Building and construction costs	156 390.87		
Less Reserve for depreciation	25 750.00	130 640.87	
Land 1915–1919 Cherry Street, Philadelphia, Pa.		29 178.61	
Total Assets Building Fund			217 871.28
Other Special and Designated Funds:			
Cash: ASTM Research Fund	9 225.18		
Dudley Medal and Marburg Lecture Fund	1 569.91		
Richard L. Templin Award Fund	67.31		
Sam Tour Award Fund	45.75		
Committee Funds	122 965.81	133 873.96	
Investments:			
ASTM Research Fund (Market Value $51 829.93)—Cost	48 313.79		
Dudley Medal and Marburg Lecture Fund (Market Value $4 697.50)—Cost	6 625.00		
Richard L. Templin Award Fund (Market Value $1 011.78)—Cost	994.62		
Sam Tour Award Fund (Market Value $1 533.00)—Cost	1 507.00		
Committee Funds (Market Value $13 581.88)—Cost	14 000.00	71 440.41	
Total Assets, Special and Designated Funds			205 314.37
Total Assets			$947 676.30

NOTE.—All market values of securities are as of December 27, 1951.

LIABILITIES

General Funds:			
Advance Collections	$5 595.58		
Accounts Payable:			
Committee C-1	31.31		
Joint Committee on X-ray Diffraction	67 363.97		
Total Current Liabilities, General Funds		$72 990.86	
Life Membership Fund	3 812.50		
Publication Fund	16 841.80		
Book of Standards Reserve	101 900.18		
Executive Retirement Reserve	16 820.00		
Retirement Fund Reserve	8 062.18		
Reserve for Depreciation of Investments	20 000.00		
Reserve for Additional Cost of Replacement of Headquarters Building	25 000.00	192 436.66	
		265 427.52	
Surplus		259 063.13	
Total Liabilities and Surplus, General Funds			$524 490.65
Building Fund:			
Contributions from Members		170 748.93	
Contributions from ASTM General Funds		5 062.23	
Accumulated Income, Profit on Investments		1 281.51	
Notes Payable to ASTM General Fund		40 778.61	
Total Building Fund			217 871.28
Other Special and Designated Funds:			
ASTM Research Fund:			
Principal	48 504.34		
Income	9 034.63	57 538.97	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	1 569.91	8 194.91	
Richard L. Templin Award Fund:			
Principal	1 006.56		
Income	55.37	1 061.93	
Sam Tour Award Fund:			
Principal	1 507.00		
Income	45.75	1 552.75	
Committee Funds, Unexpended Balances		136 965.81	
Total Special and Designated Funds			205 314.37
Total Liabilities and Funds			$947 676.30

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1947–1951 INCLUSIVE.

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1947	$3 930.42	$163 690.12	$37 218.85	$16 405.39	$7 755.95	$20 000.00	$36 070.74	$157 418.09
1948	50 691.65	191 497.99	46 748.11	17 261.45	7 777.78	40 000.00	31 260.92	227 160.50
1949	56 379.22	192 325.57	36 382.87	18 078.39	12 349.77	40 000.00	31 580.92	219 235.36
1950	147 957.36	222 662.96	50 692.18	17 959.00	59 919.59	61 900.18	65 973.89	251 477.84
1951	164 497.75	263 995.13	77 239.16	18 758.61	72 990.86	101 900.18	90 536.48	259 063.13

COMMITTEE FUNDS

Committee A-1 On Steel	$1 036.87	
Committee A-5 On Corrosion of Iron and Steel	1 164.95	
Committee B-3 On Corrosion of Non-Ferrous Metals and Alloys	2 482.83	
Committee B-6 On Die-Cast Metals and Alloys	2 645.56	
Committee B-8 On Electrodeposited Metallic Coatings	11.25	
Committee C-1 On Cement (General Funds)	764.35	
Committee C-1 Cement Reference Laboratory	240.00	
Committee C-9 Sanford E. Thompson Medal Fund	988.12	
Committee C-9 On Concrete and Concrete Aggregates	151.17	
Committee C-15 On Manufactured Masonry Units	399.83	
Committee C-18 On Natural Building Stones and Slate	509.36	
Committee D-1 On Paint, Varnish, Lacquer, and Related Products	625.03	
Committee D-2 On Petroleum Products and Lubricants	417.93	
Committee D-2 ASTM-IBM	1 994.97	
Committee D-2 D.C.C. Reference Fuel Account	18 548.88	
Committee D-2 D.C.C. National Exchange Group	2 633.23	
Committee D-2 D.C.C. Equipment Development Project	4 628.70	
Committee D-4 On Road and Paving Materials	6.95	
Committee D-5 On Coal and Coke	1 534.06	
Committee D-7 Pole Research Fund	4 000.00	
Committee D-9 On Electrical Insulating Materials	1 626.12	
Committee D-11 On Rubber and Rubberlike Materials	122.25	
Committee D-12 On Soaps and Other Detergents	371.81	
Committee D-13 On Textile Materials	876.83	
Committee D-15 On Engine Antifreezes	43.00	
Committee E-3 On Chemical Analysis of Metals	150.54	
Committee E-9 On Fatigue	200.31	
ASA Sectional Committee on Specifications for Cast Iron Pipe	1 351.40	
Detroit District Council	3 565.81	
Philadelphia District Council	352.03	
Philadelphia District (Annual Meeting Acct.)	711.31	
Pittsburgh District Council	573.35	
Western New York—Ontario District Council	221.72	
Advisory Committee on Corrosion	70 069.53	
Administrative Committee on Ultimate Consumer Goods	204.30	
Joint Committee on X-ray Diffraction	7 499.07	
Joint Committee on X-ray Diffraction Research Associate	4 242.39	
Total Committee Funds		$136 965.81
Accounted for as follows:		
Cash in bank and on hand	122 965.81	
Investments (at cost)	14 000.00	136 965.81

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, January 1, 1951:			
Principal—Investments (at cost)	$6 625.00		
Income—Cash	1 568.15	$8 193.15	
Receipts:			
Interest on investments		330.00	$8 523.15
Disbursements:			
Honorarium		200.00	
Dudley Medal		77.00	
Miscellaneous (Travel exp., etc)		51.24	328.24
			8 194.91
Accounted for as follows:			
Principal—Investments (at cost)		6 625.00	
Income—Cash in bank		1 569.91	$8 194.91

Richard L. Templin Award Fund

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, January 1, 1951	1 000.00	1 000.00	
Receipts:			
Sale of securities	6.56	−1 000.00	1 006.56
Disbursements:			
Purchase of securities		994.62	−994.62
	1 006.56	994.62	11.94
Income Account:			
Balance, January 1, 1951		57.71	
Receipts:			
Interest on investiments		25.16	82.87
Disbursements:			
Templin Awards		25.00	
Engrossing certificates		2.50	27.50
Balance, December 31, 1951			55.37

Sam Tour Award Fund

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, January 1, 1951	1 500.00	1 500.00	
Receipts:			
Sales of securities	−78.00	−1 500.00	1 422.00
From general funds	85.00		85.00
Disbursements:			
Purchase of securities		1 507.00	−1 507.00
	1 507.00	1 507.00	0.00
Income Account:			
Balance, January 1, 1951		25.75	
Receipts:			
Interest and dividends on investments		56.25	82.00
Disbursements:			
Tour Award		35.00	
Engrossing certificates		1.25	36.25
Balance, December 31, 1951			$45.75

ASTM Research Fund

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, January 1, 1951	$45 914.60	$45 772.28	$142.32
Receipts:			
Sales of investments	89.74	−5 730.95	5 820.69
From General Funds	2 500.00		2 500.00
Disbursements:			
Purchase of Investments		8 272.46	−8 272.46
	48 504.34	48 313.79	190.55
Income Account:			
Balance, January 1, 1951		7 706.99	
Receipts:			
Interest and Dividends on Investments	1 922.64		
Contributions	99.00	2 021.64	9 728.63
Disbursements:			
Mimeographing Expense		444.00	
Welding Research Council		250.00	694.00
Balance, December 31, 1951			$9 034.63

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD JANUARY 1, 1951 TO DECEMBER 31, 1951

Cash balance, January 1, 1951			$147 957.36
RECEIPTS			
Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$207 317.15		
Past Dues	1 530.90		
Advance Dues	1 495.70		
Income, Life Membership Fund	175.00		
Entrance Fees	4 505.00		
Total Dues			$215 023.75
Sales of publications:			
Book of Standards (Members, additional parts)	37 523.49		
1949 Book of Standards	73 340.53		
1950 Supplements to Book of Standards	44 760.94		
1951 Supplements to Book of Standards	254.65		
Methods of Chemical Analysis of Metals	13 750.28		
Compilations of Standards	65 802.76		
Separate Standards	24 170.54		
Selected Standards for Students	5 869.73		
Proceedings	6 140.16		
Spring Meeting Papers	1 329.58		
Bulletin Subscriptions (non-members)	2 848.72		
Special and Miscellaneous Publications	64 813.50		
Total Sales of Publications			340 604.88
Miscellaneous:			
Advertising—BULLETIN	28 775.24		
Advertising—Index	2 008.25		
Interest and Dividends	14 365.30		
Registration and Other Fees—Meetings	7 425.00		
Annual Meeting Exhibit	1 622.10		
Staff Services	2 832.29		
Miscellaneous	650.40		
Total Miscellaneous Items			57 678.58
Total Operating Receipts (Budgeted)			613 307.21
Nonoperating Receipts (Not Budgeted):			
Investments Matured or Sold	47 494.96		
Excess Remittance	2 578.57		
Committee C-1 for Technical Assistant	2 460.00		
Retirement Fund Reserve	72.59		
Executive Retirement Reserve	490.00		
Joint AIME-ASTM Publication Fund	343.70		
Sales of X-ray Diffraction Cards	45 395.93		
Institute of Petroleum Publications	340.20		
From Building Fund on Account of Loan	1 133.34		
Annual Meeting Luncheon	786.50		
Total Nonoperating Receipts		101 095.79	
Total Receipts			714 403.00
Total Receipts for 1951 and Cash Balance, January 1, 1951			$862 360.36

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$10 756.28		
1949 Book of Standards	996.42		
1950 Supplements to Book of Standards	3 703.03		
1951 Supplements to Book of Standards	33 039.13[a]		
Methods of Chemical Analysis	8 614.25		
Compilations of Standards	16 538.81		
Separate Standards	10 555.37		
Selected Standards for Students	299.33		
1950 Proceedings	4 066.33		
1951 Proceedings	34 010.56[a]		
Preprints	6 964.21		
ASTM BULLETIN	29 985.89		
Circulars to Members	2 431.53		
Index to Standards	6 654.43		
Special and Miscellaneous Publications	37 445.44		
Miscellaneous Publications—Electros, at cost	173.93		
Emergency Alternate Standards	56.07		
Total Disbursements—Publications			$206 291.01
Salaries	206 959.23		
General Office Expenses	59 867.75		
Expenses—Technical and District Committees	10 127.73		
Expenses—Meetings	12 308.84		
Headquarters Occupancy Expense (includes $5,700 depreciation on building)	18 618.11		
American Standards Association	1 500.00		
Traveling Expense, Administrative and Special Committees	6 213.72		
Furniture and Fixtures	3 489.41		
Dues, Contributions, Miscellaneous	534.90		
Legal Services	1 000.00		
Employees' Retirement Fund	15 234.33		
Federal Old Age and Survivors	2 054.32		337 908.34
Total Operating Disbursements (Budgeted)			544 199.35
Nonoperating Disbursements (Not Budgeted):			
Refund of Excess Remittances	2 578.57		
Investments	87 815.00		
Technical Assistant Committee C-1	2 478.00		
Transfer to Joint Committee on X-ray Diffraction	20 000.00		
Cost and Refunds on X-ray Diffraction Cards	6 671.83		
Institute of Petroleum Publications	350.80		
Annual Meeting Luncheon	974.40		
Transfer to Research Fund	2 500.00		
Loan to ASTM Building Fund	29 178.61		
Miscellaneous	1 116.05		
Total Nonoperating Disbursements		153 663.26	
Total disbursements			$697 862.61
Cash Balance, December 31, 1951			$164 497.75

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[a] These accounts include $41 100 representing a check drawn against cost of the 1951 *Proceedings* and 1950 Supplements to 1949 Book of Standards, but not actually paid on December 31, 1951.

ASTM BUILDING FUND

DETAILS OF BUILDING FUND CASH RECEIPTS AND DISBURSEMENTS FOR THE PERIOD JANUARY 1, 1951 TO DECEMBER 31, 1951

Cash balance, January 1, 1951		$528.61
Receipts		
Contributions from Members	$706.17	
Interest on Investments	834.19	
From ASTM General Fund:		
On Account of Depreciation on Building, Elevator, and Air Conditioning Installation	5 700.00	
On Account of Interest and Amortization of Note	1 630.89	
Loan for Purchase of Property 1915–1919 Cherry St., Phila., Pa.	29 178.61	38 049.86
		$38 578.47
Disbursements		
Purchase of 846.473 Shares Commonwealth Investment Co.	$6 196.69	
Interest on Loan from ASTM General Fund	497.55	
Reduction of Loan from ASTM General Fund	1 133.34	
Purchase of Property 1915–1919 Cherry St., Phila., Pa.	29 178.61	37 006.19
Cash balance, December 31, 1951		$1 572.28

ASTM BUILDING FUND

DETAILS OF ASSETS AND LIABILITIES OF BUILDING FUND AS OF DECEMBER 31, 1951

Assets

Cash in Girard Trust Corn Exchange Bank, Philadelphia, Pa				$1 572.28
Investments: (Market value $25 537.24)				
$8 500 U. S. Treasury Bonds, 2½s, 1972–67			$8 632.83	
5 000 U. S. Bonds, Series G, 2½s			5 000.00	
1 846.473 Shares Commonwealth Investment Co			12 846.69	26 479.52
Property 1916–1918 Race Street, Philadelphia, Pa.:				
Purchase Price	$53 625.00			
Commission to Agent	2 681.25			
Settlement Fee, net	197.10			
	$56 503.35			
Allocated to:				
Land			30 000.00	
Building		$26 503.35		
Construction Costs:				
Architect's Fees	$11 544.70			
Rent paid to facilitate possession	110.00			
Zoning fees and permits	17.50			
General contractor	86 933.72			
Air Conditioning	20 749.00			
Elevator	7 548.04			
Air Conditioning Unit	650.75			
Exhaust system for basement	216.25			
Real Estate Agent's Fee	500.00			
Soundproofing	1 953.00			
Miscellaneous	817.48			
	$131 040.44			
Less proceeds from sales and salvage of equipment and rentals	1 152.92	129 887.52		
		$156 390.87		
Reserve for Depreciation (provided from General Funds)		25 750.00	130 640.87	160 640.87
Property 1915–1919 Cherry Street, Philadelphia, Pa.:				
Purchase Price			$27 500.00	
Commission to Agent			1 375.00	
Settlement Fee, net			303.61	29 178.61
Total Assets				$217 871.28

Liabilities and Funds

Contributions from members		$170 748.93	
Contributions from ASTM General Funds		5 062.23	
Accumulated Income:			
Interest and Dividends on Investiments	$3 067.47		
Profit on disposal of securities.	76.27		
	3 143.74		
Less Interest on Loan from General Funds	1 862.23	1 281.51	
Notes payable to ASTM General Funds		40 778.61	
Total Liabilities			$217 871.28

INVESTMENTS

AS OF DECEMBER 31, 1951

GENERAL FUNDS

Par Value	*Bonds*	*Cost or Book Value*	*Market Value*[a]
$4 000	Erie R. R. Co. Gen. Conv. Income 4½s, 2015	$2 832.00	$2 820.00
20 000	Federal Intermediate Credit Bank Deb. 2.15s 2/1/52	20 000.00	19 998.00
37 600	U. S. Savings Bonds Series G 2½s	37 600.00	36 175.60
5 000	Walworth Co. 3¼s convertible debentures 1976	5 496.53	4 025.00
		65 928.53	63 018.60
Shares	*Preferred Stocks*		
25	Allis-Chalmers Mfg. Co. 3¼s cumulative convertible	2 220.60	2 537.50
67	American Airlines, Inc. 3½s cumulative convertible	5 911.55	6 030.00
50	Chicago, Rock Island & Pacific R.R. Co. 5s "A" cumulative convertible	4 434.60	4 087.50
50	Food Machinery & Chemical Co. 3¼s cumulative convertible	4 750.10	5 350.00
45	Philco Corp 3¾s Series A	4 183.15	3 690.00
		21 500.00	21 695.00
	Common Stocks		
100	Allis-Chalmers Mfg. Co., no par value	4 170.75	5 087.50
100	American Rad. & Std. Sanitary Corp	1 564.32	1 575.00
25	American Telephone & Telegraph Co	3 798.72	3 893.75
100	American Tobacco Co	7 370.97	6 150.00
60	American Viscose Corp	2 323.58	3 960.00
50	American Cyanamid Co	3 669.14	5 800.00
50	Aluminum Co. of America	3 679.74	4 000.00
100	Baldwin-Lima Hamilton Corp	3 822.00	1 087.50
100	Baldwin Securities Corp	375.00	387.50
115	Carpenter Steel Co	6 104.75	5 692.50
100	Chase National Bank	3 412.50	3 850.00
15	Delaware Power & Light Co	235.00	390.00
50	Dow Chemical Co	3 944.32	5 750.00
100	General Telephone Corp	3 312.82	3 000.00
200	Gulf Oil Corp	6 273.27	10 725.00
300	International Harvester Co	9 610.00	10 500.00
300	Lone Star Cement	7 412.17	7 387.50
45	Montgomery Ward & Co	2 646.41	3 020.63
100	Ohio Oil Co	2 623.35	5 375.00
200	Philadelphia Electric Co	4 352.72	5 825.00
125	Public Service Elec. & Gas Co	4 558.50	3 000.00
50	Republic Steel Corp	2 152.93	2 100.00
100	Socony-Vacuum Oil Co	2 510.28	3 437.50
30	United Gas Improvement Co	567.50	937.50
		90 490.74	102 931.88
	Mutual Funds		
257	Broad Street Investing Corp	5 071.02	5 520.36
525	Commonwealth Investment Co	3 491.25	3 564.75
1 997	Eaton & Howard Balanced Fund	60 173.33	61 228.02
964	Fundamental Investors, Inc	17 340.26	18 769.08
		$86 075.86	$89 082.21

ASTM BUILDING FUND

Par Value	*Bonds*	*Cost or Book Value*	*Market Value*
$8 500	U. S. Treasury, 2½s 1972–67	$8 632.83	$8 149.38
5 000	U. S. Savings Bonds, series G 2½s	5 000.00	4 845.00
		13 632.83	12 994.38
Shares	*Mutual Funds*		
1 846 473	Commonwealth Investment Co	12 846.69	12 537.55

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[a] **Market values were taken from current financial publications as of close of market December 27, 1951.**

ASTM RESEARCH FUND

	Bonds		
$1 500	B. & O. Gen. & Ref. 5s, Series M, 1996	1 511.25	1 065.00
9 900	U. S. Defense Savings bonds, Series G, 2½s	9 900.00	9 545.40
2 000	U. S. Treasury bonds, 2½s, 1970–65	2 000.00	1 923.75
		13 411.25	12 534.15
Shares	*Preferred Stocks*		
30	Allis-Chalmers Mfg. Co., 3¼ cumulative convertible	3 007.22	3 045.00
33	American Airlines, Inc., 3½ cumulative convertible	3 366.00	2 970.00
12	Consolidated Edison Co. of N. Y., $5	1 234.39	1 284.00
29	Consumers Power Co., $4.50	2 914.50	2 958.00
20	Philco Corp., 3¾, Series A	2 030.00	1 640.00
		12 552.11	11 897.00
Shares	*Common Stocks*		
100	Allis-Chalmers Mfg. Co.	4 421.59	5 087.50
196	General Motors Corp.—gift[a]	6 504.75	10 167.50
100	Jones & Laughlin Steel Corp	2 636.06	2 437.50
55	Montgomery Ward Co.	3 151.63	3 691.88
		16 714.03	21 384.38
Shares	*Mutual Funds*		
280	Broad Street Investing Corp	5 636.40	6 014.40

DUDLEY MEDAL AND MARBURG LECTURE FUND

Par Value	*Bonds*	*Cost or Book Value*	*Market Value*
$500	B. & O. R.R. Ref. & Gen. Mtg., 6s, Series J, 1995	$550.00	$415.00
6 000	B. & O. R.R. Ref. & Gen. Mtg., 5s Series G, 1995	6 075.00	4 282.50
		$6 625.00	$4 697.50

RICHARD L. TEMPLIN AWARD FUND

33	Eaton & Howard Balanced Fund	$994.62	$1 011.78

SAM TOUR AWARD FUND

50	Eaton & Howard Balanced Fund	$1 507.00	$1 533.00

COMMITTEE FUNDS

$1 000	U. S. Treasury Bonds, 2⅞s, 1960–55	$1 000.00	$1 050.00
2 000	U. S. Treasury Bonds, 2½s, 1969–64	2 000.00	1 925.00
3 000	U. S. Treasury Bonds, 2½s, 1970–65	3 000.00	2 885.63
3 000	U. S. Treasury Bonds, 2½s, 1972–67	3 000.00	2 876.25
5 000	U. S. Savings Bonds, Series G, 2½s	5 000.00	4 845.00
		$14 000.00	$13 581.88

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[a] The income from these shares is, by agreement, paid to an annuitant.

APPENDIX II

REPORT OF ADMINISTRATIVE COMMITTEE ON STANDARDS

The Administrative Committee on Standards has, in accordance with its duties, carried out over the year various activities. Its principal function, however, has been in acting upon tentatives and revisions which have been submitted to it. Hereinafter is included a complete record of such recommendations as have been approved.[1] These actions include 53 new tentatives accepted during the year as well as revisions of 75 tentatives, tentative revisions of 13 standards, 16 standards reverted to tentative, and 11 standards and tentatives withdrawn. The majority of these were acted upon at meetings of the committee held on September 12, 1951, February 15, 1952, and May 14, 1952, and the remainder were handled by correspondence.

The committee has continued its efforts toward improvement of quality and form of standards. At the instance of the committee, the Board of Directors has arranged with Committee E-1 for preparation of a manual on the form of ASTM methods for guidance of the technical committees. It is planned that when this manual is completed it will be put in the hands of subcommittee and group leaders engaged in the writing of methods of testing as well as in the hands of technical committee chairmen and officers. It is hoped that this procedure will insure more adequate treatment of certain important features such as editorial form, accuracy, reproducibility, etc.

Since several technical committees of the Society have found need for some special provisions to be made in their standards in view of the present emergency conditions, a Procedure for Emergency Alternate Provisions and Emergency Standards was adopted by the board of Directors and appears in the Year Book as an appendix to the Regulations Governing Technical Committees. Emergency alternate provisions with respect to 33 specifications have been accepted by the Administrative Committee on Standards. These were submitted by Committees A-1 on Steel, A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, and D-11 on Rubber and Rubber-like Materials. A list of the emergency alternate provisions is included in the respective reports of the above committees.

Expansion of Standardization Activities

Of the projects referred to in the report of a year ago, organization has now been effected of the following committees:

D-23 on Cellulose and Cellulose Derivatives
E-14 on Mass Spectrometry

Smooth Surface Organic Floor Coverings.—The study mentioned in previous reports with respect to the Society organizing a new committee to deal with asphalt floor tile and other smooth surface floor coverings is still under way.

Gasket Materials.—Consideration is being given to the desirability of expanding the work which has been done in the Society on rubber gaskets and the formation of a new committee to cover all gasket materials.

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[1] This list is not reproduced here, since the recommendations have all been announced currently throughout the year in the ASTM Bulletin.—Ed.

Other Pending Proposals.—At various times inquiries have been received and proposals have been submitted with respect to the Society undertaking work in the field of ore sampling, surface chemistry, abrasives, and water-repellent solutions for masonry surfaces.

RELATIONS WITH AMERICAN STANDARDS ASSOCIATION

Two methods under the procedure of the American Standards Assn. are used by ASTM in submitting recommendations to the ASA. One is a combination of the so-called existing standards procedure and the proprietary sponsorship procedure. On the initial reference of an existing ASTM standard to the ASA, it is submitted under the existing standards procedure with a supporting statement giving a history of the development of the standard and indicating the degree of its acceptance. If the standard is approved as American Standard, the ASTM is granted proprietary sponsorship so far as any future revisions are concerned, and such revisions are brought to the attention of the ASA currently for approval under this proprietary sponsorship procedure.

The second method consists of having standards reviewed in a sectional committee made up of representatives of a number of interested organizations but with ASTM as sponsor or co-sponsor for the sectional committee.

Standards Submitted under the Existing Standards Procedure.—The following standards were submitted to the American Standards Assn. for approval as American Standard under the existing standards procedure:

Standard Method of Test for Calorific Value of Gaseous Fuels by the Water Flow Calorimeter (D 900 – 48), and

Standard Definitions of the Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 – 44).

Revised Standards Submitted Under Proprietary Procedure.—In view of the Society having been designated as proprietary sponsor for the revisions of ASTM standards that had been approved as American Standard under the existing standards procedure, it has submitted to the American Standards Assn. during the year revisions of one specification relating to carbon and alloy steel nuts, 1 relating to thermal analysis of steel, 8 relating to copper and brass material, 1 relating to sand-lime brick, 1 relating to turpentine, and 3 relating to soap.

Standards Submitted under Sectional Committee Procedure.—During the year, reports were received from 6 of the sectional committees for which the Society is sponsor or co-sponsor as follows:

Sectional Committee A88 on Magnesium Oxychloride Cement Flooring.—This committee has recommended the approval as American Standard of 4 specifications and the approval of revisions of 3 American Standards.

Sectional Committee C7 on Bare Electrical Conductors.—This committee has recommended the approval of revisions of 5 American Standards; it has also recommended that the ASTM Specs. for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 – 50 T) replace the American Standard for Physical and Electrical Properties of Hard-Drawn Aluminum Conductors (ASA No. C11-1927).

Sectional Committee C59 on Electrical Insulating Materials.—This Committee has recommended the approval as American Standard of 1 ASTM Method, and the approval of revisions of 3 American Standards.

Sectional Committee J6 on Rubber Protective Equipment for Electrical Workers.

—This committee has recommended the approval of revisions of an American Standard.

Sectional Committee L14 on Textile Test Methods.—This committee has recommended the approval of revisions of 3 American Standards.

Sectional Committee Z11 on Petroleum Products and Lubricants.—This committee has recommended the approval as American Standard of 6 ASTM methods, the approval of revisions of 7 American Standards, and the withdrawal of an American Standard.

All of these reports have been referred to the American Standards Assn. The recommendations of Sectional Committees J6 and Z11 have been approved; action is still pending so far as the recommendations of the other committees are concerned.

INTERNATIONAL RELATIONS

The Society continues to receive from other countries standards with the request for comment. ASTM committees review these standards, and frequently suggestions result. Apart from such informal cooperation, however, quite a number of proposals have been received through the American Standards Assn. concerning projects that have been proposed under the International Organization for Standardization (ISO).

Textiles.—The general secretariat for ISO/TC 38 has been assigned to Great Britain, but America holds the secretariat for several subcommittees. American participation in the work of ISO/TC 38 is being handled by a special committee organized in the American Standards Assn. under the sponsorship of ASTM and the American Association of Textile Chemists and Colorists, with representation from the various groups interested, which committee has been given the designation "L23."

Meetings are being held in New York in June of this year of the subcommittees on shrinkage of fabrics in washing, and on yarn testing, as well as the working group on cloth strength testing using the grab technique. It is expected that the subcommittee on colorfastness will meet in New York in November.

Petroleum Products.—The American Standards Assn. as the official American member of ISO has asked Sectional Committee Z11, of which ASTM is sponsor, to handle the secretariat for ISO/TC 28. The American Petroleum Institute has raised funds to support the work of the secretariat for one year, and a group set up under that organization will function in the handling of the actual details of this secretariat.

A meeting of ISO/TC 28 is to be held in New York City in June, 1952.

Rubber.—The secretariat for ISO/TC 45 is held by Great Britain. ASTM Committee D-11 is looked to to handle the American contacts with this ISO committee. A meeting of ISO/TC 45 was held in Oxford, England, October 1–4, 1951, at which America was represented by R. D. Stiehler, R. S. Havenhill, H. C. O'Brien, and Irene Levene.

Viscosity. — The Subcommittee on Rheological Properties of ASTM Committee E-1 on Methods of Testing has indicated that it favors American participation in the work of ISO/TC 66 on Viscosity. The subcommittee also favors acceptance of the secretariat by America.

Plastics.—America holds the secretariat for ISO/TC 61 on Plastics. ASTM Committee D-20 is being looked to to handle the work of this secretariat and has organized for the purpose a special committee consisting of representatives of the various groups interested.

The next meeting of ISO/TC 61 is scheduled for October, 1952, in Turin, Italy.

Shellac.—Subcommittee XIII on Shellac of ASTM Committee D-1 has been set up as the American committee in charge of contacts with ISO/TC 50 on Lac for which India holds the secretariat. America has submitted a number of comments with respect to standards dealing with shellac that are now under consideration.

A meeting of the ISO committee will be held in New York City in June, 1952.

Solid Mineral Fuels.—ASTM Committee D-5 is being looked to to handle American contacts with the ISO/TC 27. A meeting of the ISO committee was held in London, England, December 10–14, 1951, at which America was represented by Mr. W. A. Selvig.

Iron and Steel.—ASTM Committee A-1 on Steel has indicated that it favors American participation in the work of ISO/TC 17 on the basis of an observer. A meeting of the ISO committee is scheduled for New York in June, 1952.

Chemistry. — The following ASTM committees have indicated an interest in the work of ISO/TC 47 on Chemistry:

D-1 on Paint, Varnish, Lacquer, and Related Products
D-3 on Gaseous Fuels
D-12 on Soaps and Other Detergents

Laboratory Glassware.—Committee E-1 on Methods of Testing has indicated that it favors American participation in the work of ISO/TC 48 on the basis of an observer.

General Definitions Relating to Chemical and Physical Test Results.—ASTM Committee E-11 favors American participation in the work of ISO/TC 69 and it is proposed to discuss with the American Standards Assn. the manner of participation by this country.

A meeting of ISO/TC 69 was held in Geneva, Switzerland, on November 26–30, 1951, which was attended by W. Edwards Deming, member of ASTM Committee E-11 on Quality Control.

Mica.—Subcommittee IX on Mica of ASTM Committee D-9 has been set up to handle the American contacts with this ISO Committee 56 for which India holds the secretariat. A number of comments have been submitted by the American committee with respect to standards dealing with mica that are now under consideration.

A meeting of ISO/TC 56 is scheduled for New York City during June of this year.

Copper and Copper Alloys.—America holds the secretariat for the ISO/TC 26, and a group is being organized under ASTM Committee B-5 to handle the American contacts with this ISO committee as well as the duties of the secretariat.

Paper.—ASTM Committee D-6 on Paper and Paper Products has indicated that it favors American participation in the work of the ISO/TC 6 on the basis of an observer.

Timber.—ASTM Committee D-7 on Wood has indicated that it favors American participation in the work of ISO committee 55.

Respectfully submitted on behalf of the committee,

L. B. JONES,
Chairman.

R. E. HESS,
Secretary.

APPENDIX III

REPORT OF ADMINISTRATIVE COMMITTEE ON RESEARCH

The Administrative Committee on Research held one meeting, on April 14, 1952, since its report to the Board of Directors a year ago. At this meeting the status of the Research Fund was reviewed. The committee authorized a contribution of $250 to the Welding Research Council, which it has been making annually, and also the payment of $444 to S. H. Ingberg for the compilation and evaluation of flame-spread data, which was completed during the year.

The committee approved the transfer of $5000 from the present balance in the Income Account to the Principal Account of the ASTM Research Fund, and the investment of this sum in the Eaton and Howard Mutual Balanced Funds.

Statements submitted by the technical committees have been compiled into a publication entitled, "Some Unsolved Problems." This publication will be brought to the attention of Engineering and Science colleges and to research organizations in case research might be conducted in the areas covered. These "Problems" are being published serially in the ASTM BULLETIN, and it is hoped that additional problems will be submitted by the technical committees from time to time as a continuing effort to develop new techniques and needed data.

The Joint Committee on Effect of Temperature on the Properties of Metals is currently raising $85,000 to study the effect of temperature on the properties of metals. It is encouraging to report that the Joint Committee and Committee A-3 on Cast Iron are cooperating in the study of effects of temperature on the properties of cast iron, and that $10,000 is to be allocated for this work by the Joint Committee from its anticipated goal of $85,000. Committee C-8 on Refractories has obtained the assistance of the Special Refractories Association in its effort to establish definitions and nomenclature for refractory materials. This initial study will be followed by research work to provide the basis for the preparation of test procedures for spalling, shrinkage, etc. Committee D-7 on Wood expects to reactivate its subcommittee to raise a fund of $100,000 for the testing of wood poles. Committee E-9 on Fatigue has set a goal of $1,000,000 for a study of fatigue as related to large machines and test correlation. The Advisory Committee on Corrosion has passed its goal of $100,000 as a minimum for the establishment and maintenance of exposure test sites for a 10-year period. The Joint Research Committee on Boiler Feed Water Studies is presently exploring the possibilities for support of a research project on controlling corrosion of steel by boiler water. The work on X-ray diffraction cards has received further indirect support by a grant to the National Bureau of Standards by the Air Force for the development of new data. The Society will have access to these data to augment data already in hand. These activities point to the possibility of further financial assistance to technical committees for research, provided an approach is properly organized.

The Society has continued its relations with the Division of Engineering and Industrial Research of the National Research Council, and the activities of the Highway Research Board and the Building Research Advisory Board of this Division have been of considerable interest to the Society.

The present chairman was re-elected for a term of two years, and J. S. Pettibone of the Headquarters Staff was asked to serve as secretary of the committee.

Respectfully submitted on behalf of the Committee,

W. C. VOSS,
Chairman.

J. S. PETTIBONE,
Secretary.

APPENDIX IV

REPORT OF ADMINISTRATIVE COMMITTEE ON PAPERS AND PUBLICATIONS

The activities of the Administrative Committee on Papers and Publications have been largely one of reviewing material for publication and in planning for its publication, and also in planning the large technical program for the Fiftieth Anniversary Meeting. This report is largely one of a record of the various regular and special publications that have been issued during the past year.

It may be of interest to note that apart from the regular publications such as *Proceedings* and Book of Standards, 25 publications were issued by the Society during the past year (including 10 compilations issued during the first half of this year). Also 4 reprints of publications have been struck off as listed later in this report.

In August, 1950, a Study Committee was appointed consisting of L. S. Reid, chairman, L. A. Melsheimer, and C. H. Sample to review critically the new method of publication of the Book of Standards and to see if any changes were indicated. This committee studied the work of the former committee headed by J. C. Geniesse and was in accord with the main findings of that committee—namely, that the Book of Standards should not be published in loose-leaf form; it should be published triennially, and it should not be broken down into separate volumes such as the compilations. After reviewing all factors up to the present time, the committee recommended that the Book of Standards should be published in the present format and binding; the next edition should be published in seven parts due to the increase in material, particularly as pertains to Part 5; and that Bible paper should be used to cut down weight and size of volume.

RECORD OF PUBLICATIONS ISSUED THIS YEAR

Regular Publications:

1951, *Proceedings* 1332 pp., 7300 copies.
1951 Supplements to the Book of Standards
  Part 1, 416 pp., 9500 copies.
  Part 2, 360 pp., 8000 copies.
  Part 3, 281 pp., 7250 copies.
  Part 4, 269 pp., 7000 copies.
  Part 5, 341 pp., 7000 copies.
  Part 6, 249 pp., 6500 copies.
1951 Year Book, 608 pp., 7100 copies.
1951 Index to ASTM Standards, 282 pp., 22,500 copies.
ASTM BULLETIN, 8 issues (May, 1951, to April, 1952) total number of pages, 716, average number of copies 11,215.

A statement of the volume of the principal publications for the past four years is given below:

Publications	1948 pages	1949 pages	1950 pages	1951 pages
Proceedings	1366	1252	1480	1332
Book of ASTM Standards	....	8396	....	....
Supplements to Book of ASTM Standards	1648	....	2179	1916
ASTM Methods of Chemical Analysis of Metals	....	....	486	....
Index to ASTM Standards	272	280	274	282
Year Book	569	570	588	608
Spring Meeting Symposiums	....	78	....	63
ASTM BULLETIN	664	728	772	716
Totals	4519	11304	5779	4917

Special Compilations of Standards Published from April 15, 1951 to April 15, 1952:

Specifications for Steel Piping Materials (A-1), 382 pp., 2500 copies.

Specifications for Carbon and Alloy-Steel Plates for Boilers and Pressure Vessels (A-1), 56 pp., 1600 copies.

Specifications for Rolled Structural Steel (A-1), 40 pp., 2000 copies.

ASTM Standards on Copper and Copper Alloys (B-5), 516 pp., 1100 copies.

ASTM Standards on Cement (C-1), 253 pp., 2250 copies.

Manual of ASTM Standards on Refractory Materials (C-8), 304 pp., 4600 copies.

ASTM Standards on Petroleum Products and Lubricants (D-2), 804 pp., 6800 copies.

ASTM Standards on Bituminous Constructional Materials (D-4, D-8), 342 pp., 1200 copies.

ASTM Standards on Coal and Coke (D-5), 159 pp., 2000 copies.

ASTM Standards on Electrical Insulating Materials (D-9), 700 pp., 1200 copies.

ASTM Standards on Textile Materials (D-13), 611 pp., 2200 copies.

ASTM Standards on Engine Antifreezes (D-15), 44 pp., 1000 copies.

Special Compilations of Standards in Prospect:

ASTM Standards on Rubber and Rubber-Like Materials (D-11), 676 pp., 1750 copies.

ASTM Standards on Plastics (D-20), 650 pp., 2000 copies.

Special Publications Issued:

Summary of Proceedings of the Fifty-fourth Annual Meeting, 26 pp., 7000 copies.

1951 Edgar Marburg Lecture "Corrosion Testing" by F. L. LaQue, 92 pp., 2500 copies.

Monograph on Paper and Paperboard (STP 60-A), 136 pp., 2500 copies.

Symposium on Triaxial Testing of Soils and Bituminous Materials (STP 106), 309 pp., 2000 copies.

Symposium on Methods of Measuring Viscosity at High Rates of Shear (STP 111), 53 pp., 2000 copies.

Symposium on Thermal Insulating Materials (STP 119), 63 pp., 2000 copies.

Papers on Evaluation of Soaps and Detergents (STP 115), 64 pp., 1500 copies.

Symposium on Bulk Sampling (STP 114), 71 pp., 2500 copies.

Symposium on Flame Photometry (STP 116), 126 pp., 2500 copies.

Special Publications Issued (continued):

Symposium on Structural Sandwich Construction (STP 118), 120 pp., 2000 copies.

Papers on Statistical Aspects of Fatigue (STP 121), 70 pp., 2000 copies.

"Changes in Characteristics of Portland Cement as Exhibited by Laboratory Tests Over the Period 1904 to 1950," by H. F. Gonnerman and William Lerch (STP 127), 60 pp., 500 copies.

Report of the Elevated-Temperature Properties of Stainless Steels (STP 124), 120 pp., 2000 copies.

Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions (STP 125), 29 pp., 1500 copies.

Standard Specifications for Gypsum Plastering, 16 pp., 25,000 copies.

Special Publications in Prospect:

Symposium on Measurement of Consumer Wants (STP 117), 70 pp., 2500 copies.

Symposium on Surface and Subsurface Reconnaissance (STP 122), 225 pp., 2000 copies.

Symposium on Acoustical Materials (STP 123), 56 pp., 1500 copies.

Symposium on Consolidation Testing of Soils (STP 126), 100 pp., 2000 copies.

Symposium on Insulating Oil, 45 pp., 2000 copies.

Symposium on Chemical Analysis of Inorganic Solids by Means of the Mass Spectrometer, 45 pp., 2000 copies.

Metal Cleaning Bibliography, 120 pp., 1500 copies.

Bibliography of Electrical Contacts (STP 56), 250 pp., 1500 copies. This will be cumulative and will supersede previous editions of supplements.

Manual on Engine Antifreezes (STP 120), 16 pp., 2000 copies.

ASTM—IP Manual of Oil Measurement Tables, 500 pp., 5000 copies.

ASTM Manual of Engine Test Methods for Rating Fuels (D-2), 340 pp., 3000 copies.

Proposed Procedure for Emission Spectrochemical Analysis (E-2), 200 pp., 2000 copies.

Specifications for Magnesium Oxychloride Flooring Materials, 28 pp., 5000 copies.

50-Year Index to Technical Papers and Report, 500 pp., 2500 copies.

Index to the Literature on Spectrochemical Analysis, 200 pp., 2000 copies.

Reprints:

Radiography of Steel Castings, 25 sets each of X-ray and Gamma-ray, 32 negatives in each.

Symposium on Rapid Methods for the Identification of Metals (STP 98), 77 pp., 1200 copies.
Manual on Quality Control of Materials (STP 15-C), 141 pp., 8000 copies.
Revised Cotton Yarn Appearance Standards (STP 49), 5 boards per set.

CURRENT ACTIVITIES

A very full program is in prospect for the 1952 Annual Meeting, with a number of symposiums and special sessions scheduled as follows:

Symposium on Tin—under the auspices of Committee B-2 on Non-Ferrous Metals and Alloys
Symposium on Test Methods for Process Control in Ceramic Whitewares—under the auspices of Committee C-21 on Ceramic Whitewares
Symposium on Fretting Corrosion—under the auspices of Committee D-2 on Petroleum Products and Lubricants
Symposium on Recent Developments in the Evaluation of Natural Rubber—under the auspices of Committee D-11 on Rubber
Symposium on Testing Adhesives for Durability and Permanence—under the auspices of Committee D-14 on Adhesives
Symposium on Exchange Phenomena in Soils—under the auspices of Committee D-18 on Soils for Engineering Purposes
Symposium on Direct Shear Testing of Soils—under the auspices of Committee D-18 on Soils for Engineering Purposes
Symposium on Continuous Analysis of Industrial Water and Industrial Waste Water—under the auspices of Committee D-19 on Industrial Water
Symposium on Plastics Testing—Present and Future—under the auspices of Committee D-20 on Plastics
Symposium on Conditioning and Weathering—under the auspices of Committee E-1 on Methods of Testing
Symposium on Determination of Elastic Constants—under the auspices of Committee E-1 on Methods of Testing
Symposium on Light Microscopy—under the auspices of Committee E-1 on Methods of Testing
Symposium on Strength and Ductility of Metals at Elevated Temperatures with Particular Reference to Effects of Notches and Metallurgical Changes—under the auspices of the Joint Committee on Effect of Temperature on the Properties of Metals
Symposium on Fatigue with Emphasis on Statistical Approach—under the auspices of Committee E-9 on Fatigue
Session on Factors Affecting the Durability of Concrete—under the auspices of Committee C-9 on Concrete and Concrete Aggregates
Session on Paint—under the auspices of Committee D-1 on Paint, Varnish, Lacquer, and Related Products
Session on Textiles—under the auspices of Committee D-13 on Textiles
Session on Electron Microscopy—under the auspices of Committee E-4 on Metallography
Session on Fatigue—under the auspices of Committee E-9 on Fatigue
Session on Interpretation of Non-Destructive Tests—under the auspices of Committee E-7 on Non-Destructive Testing

In addition to the above, there are a number of other technical papers which will be presented at the Annual Meeting. A number of papers are being offered to the Society for publication but not presentation at a meeting. These for the most part will be published currently in the ASTM BULLETIN or in the *Proceedings*.

Respectfully submitted on behalf of the committee,

R. E. HESS,
Secretary.

APPENDIX V

REPORT OF ADMINISTRATIVE COMMITTEE ON SIMULATED SERVICE TESTING

The Administrative Committee on Simulated Service Testing held its last meeting at Society Headquarters on October 30, 1951, which was attended by a number of the ASTM staff members whose familiarity with technical committee activities has proven to be of material assistance in ACSST discussions.

Reports of the status of activities discussed at the previous meeting show that:

1. Committee E-1 on Methods of Testing (Subcommittee 14) has accepted the ACSST recommendation for work leading to the establishment of standard conditions for suitable humidity testing procedures. It may now be reported that this subcommittee is actively engaged in these considerations and has already reviewed the test requirements of the Government as well as other currently used methods.

2. In view of the present activity in the American Welding Society with respect to soldering, it was considered advisable to table the subject of strength of soldered joints until it could be determined if this group intended to cover this phase of the solder work.

3. With the increasing importance and diversity of gasket materials, the committee is of the opinion that it would be preferable to gather a broad picture of the present and potential field before making any recommendations for Society activities in gasket specifications. To this end, it was requested that a Headquarters survey be made which would classify gasket applications as follows:

(*a*) Classification as to end use.
(*b*) Definition of requirements for each class.
(*c*) Indication as to materials for each requirement.

From the above, it should be possible to determine the best location (or locations) in the Society for the handling of specifications for these materials.

4. Committee D-2 on Petroleum Products and Lubricants is sponsoring a Symposium on Fretting Corrosion to be held at the 1952 Annual Meeting of the Society. The first suggestion that such a symposium be held originated in the Administrative Committee on Simulated Service Testing. The proposed program was reviewed, and comments of the committee have been passed on to the Symposium Committee.

5. Committee E-1 has decided to organize a group on bend testing, and the ACSST suggested several possibilities for the handling of this work.

6. S. A. Gordon of Battelle Memorial Institute has agreed to write for ASTM publication an article on the philosophy of simulated service testing.

The following items were also discussed and are retained for further attention:

1. Revision of list of potential projects. A new list will be prepared from many suggestions received, and this will be circulated to members for establishing priority ratings.

2. Elastomers, gaskets, etc., at low

temperature—reference to E-1 and Joint Committee on Effect of Temperature.

3. Control of temperatures on low-temperature impact tests—inquiry to Committee E-1.

4. A project for gathering handbook type data on environmental testing and standardization of such tests. It was decided this matter should be handled by Committee E-1 and the Headquarters staff.

The committee has no specific recommendations to present at this time.

Respectfully submitted on behalf of the committee,

L. L. WYMAN,
Chairman.

R. E. HESS,
Secretary.

REPORT OF COMMITTEE A-1

ON

STEEL*

Committee A-1 has been extremely active since the 1951 Annual Meeting of the Society. In fact, at the February 15, 1952, meeting of the Administrative Committee on Standards, on the recommendation of Committee A-1, 5 new specifications and revisions of 36 specifications were approved for publication. The actions at this meeting alone could be compared to the actions proposed by the committee at the 1951 Annual Meeting, where 5 new specifications and revisions of 42 specifications were covered. Other actions during the year included the revision of 8 more specifications and the issuance of emergency alternate provisions affecting 22 specifications, making a grand total in excess of the Committee A-1 actions at the 1951 Annual Meeting.

The new specifications are considered particularly significant because of the needs expressed by industry for coverage of these materials, including (*1*) nominal 9 per cent nickel steel plate for pressure vessels, (*2*) steel forgings for low-temperature service, (*3*) steel castings for low-temperature service, (*4*) high-alloy steel castings for high-temperature service, and (*5*) quenched-and-tempered alloy steel bolts and studs. The other actions on revised specifications were too numerous to cover here, but many of these also were important to the steel industry. The emergency alternate provisions provide a permissible check analysis phosphorus maximum of 0.045 per cent in tubular specifications. For specifications including chromium-molybdenum grades of steel, the emergency provisions provide a 0.40 per cent minimum limit for the molybdenum content of grades containing approximately one-half per cent molybdenum, and a 0.80 per cent minimum limit for grades containing approximately one per cent molybdenum.

Also emergency provisions for 2 specifications covering steel tires for railroad service have permitted the maximum phosphorus and sulfur limits for acid steel to be raised to 0.06 per cent and have increased the manganese range for heat-treated tires to 0.50 to 0.90 per cent.

The mid-winter series of meetings of the committee were held in Philadelphia, Pa., on January 28 to 31, inclusive. Although a freight derailment near Paoli caused all members from the West to be from 2 to 4 hours late on January 28, most of the meetings were extremely well attended and many actions on standards were taken, as reflected by the Appendix to this report. The high point of the meeting was the presentation of a paper on the significance of the impact test by H. L. Fry of the Bethlehem Steel Co., with accompanying high speed motion pictures. This paper is also being given during the 1952 Annual Meeting.

As reported during the past two years, the various product subcommittees are developing mechanical testing procedures for the products under their jurisdiction. Appended are proposed Tentative Methods and Definitions for the Mechanical Testing of Structural Steel.[1] Subcommittee XIII has under way a manual on the mechanical testing of steel products, in which it is planned to incorporate the proposals of the product subcommittees on proper techniques for the various products.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Personnel.—As a result of personnel changes during the past year, the committee now consists of 280 voting members, including 136 producers, 104 consumers, and 40 general interest members.

At the June, 1951 meeting, M. V. Healey of the General Electric Co. and A. O. Schaefer of the Midvale Co. were nominated to represent Committee A-1 on Committee E-7 on Non-Destructive Testing. Also E. V. Bennett of the Bethelehem Steel Co. was nominated as Society representative on ASA Sectional Committee B-17 for Shafting. The following men were appointed to the A-1 Advisory Committee for two-year terms:

L. B. Jones, Consulting Engineer
C. L. Clark, Timken Roller Bearing Co.
W. F. Collins, N. Y. Central System
C. L. Kent, Jones & Laughlin Steel Corp.
T. W. Merrill, Vanadium Corp.
T. R. Weber, American Locomotive Co., Railway Steel Spring Division

As a result of the January, 1952, meeting, W. H. Mayo of the U. S. Steel Co., Gordon Meldrum of the Republic Steel Corp., and H. L. Fry of the Bethlehem Steel Co. were nominated to represent Committee A-1 on Subcommittee 4 on Tension Testing of Committee E-1. Also G. A. Remley of the Westinghouse Electric Corp., and Jonathan Jones, Fabricated Steel Construction, Bethlehem Steel Co., were nominated to two-year terms on the A-1 Advisory Committee.

H. P. Bigler has acted as chairman of Subcommittee V on Steel Reinforcement Bars since 1938, during which time noteworthy progress on development of this field has occurred. Following his resignation, A. C. Weber of Laclede Steel Co. was appointed as the new chairman.

The chairmanship of Subcommittee VII on Rolled Steel Wheels and Tires has been held since 1928 by R. W. Steigerwalt of the U. S. Steel Co. Because of retirement, Mr. Steigerwalt has tendered his resignation as chairman and C. B. Bryant of the Wrought Steel Wheel Industry has been appointed in his place.

Subcommittee XXII on Valves, Fittings, Piping, and Flanges for High-Temperature and Subatmospheric Temperatures lost an eminent leader when A. E. White of the Edison Electric Institute, Chairman since 1932, resigned as chairman of that subcommittee. Mr. White is a Past President of ASTM, and was on the Board of Directors for many years. His successor is C. A. Kelting, Consolidated Edison Co. of New York.

Last year it was reported that J. J. Kelley of the Pittsburgh Screw and Bolt Co. was appointed as chairman of Subcommittee XXVI on Bolting. Because of change of duties in his company Mr. Kelley has since resigned his chairmanship, and A. S. Jameson of the International Harvester Co., former vice-chairman has been appointed chairman.

For contributing generously of their services to Committee A-1 throughout the years, J. Roy Tanner, Tanner and Arnold, and R. W. Steigerwalt, retired, U. S. Steel Co., have been elected Honorary Members of Committee A-1. Mr. Tanner was particularly active in the work of Subcommittee IX on Steel Tubing and Pipe and Subcommittee XXII on Materials for High Temperature Service. Mr. Steigerwalt was for 23 years Chairman of Subcommittee VII on Rolled Steel Wheels and Tires and cooperated in Committee A-1 work in many other ways.

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[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 1.

The committee records with regret the death during the past year of several present and former long-time members of Committee A-1, including J. A. Hance, P. L. Irwin, H. A. Grove, C. R. Pflasterer, and H. E. Smith. Mr. Hance was a representative of the Baldwin Locomotive Works as was Mr. Irwin, his successor. Mr. Grove represented the Claymont Steel Corp. and Mr. Pflasterer, the Union Pacific Railroad Co. Engineer of Materials for the New York Central until his retirement in 1932, Mr. Smith was elected to Honorary Membership in the Society in 1940.

Committee A-1 lost one of its best friends, earliest secretaries, and long-time members while this report was being written. C. L. Warwick, Executive Secretary of the Society, collapsed and died on April 23, 1952.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

During the past year the Administrative Committee on Standards has accepted the following emergency alternate provisions on the dates indicated:

Designation	*Standard Specifications for:*	Date
EA - A 26	A 26 - 39	August 21, 1951
EA - A 249	A 249 - 47	July 10, 1951
EA - A 268	A 268 - 47	July 10, 1951
EA - A 269	A 269 - 47	July 10, October 18, 1951
EA - A 270	A 270 - 50	July 10, 1951
EA - A 271	A 271 - 47	July 10, October 18, 1951
	Tentative Specifications for:	
EA - A 158	A 158 - 52 T	March 28, April 30, 1952
EA - A 161	A 161 - 51 T	March 28, 1952
EA - A 182	A 182 - 52 T	March 28, 1952
EA - A 199	A 199 - 51 T	July 10, 1951
EA - A 200	A 200 - 51 T	July 10, 1951
EA - A 206	A 206 - 52 T	March 28, 1952
EA - A 209	A 209 - 51 T	March 28, 1952
EA - A 213	A 213 - 51 T	July 10, 1951
EA - A 217	A 217 - 49 T	March 28, 1952
EA - A 250	A 250 - 51 T	March 28, 1952
EA - A 280	A 280 - 52 T	March 28, 1952
EA - A 312	A 312 - 51 T	July 10, October 18, 1951
EA - A 315	A 315 - 52 T	March 28, 1952
EA - A 329	A 329 - 50 T	August 21, 1951
EA - A 335	A 335 - 52 T	March 28, April 30, 1952
EA - A 352	A 352 - 52 T	March 28, 1952

Revisions of three existing emergency alternate provisions were also approved by the Administrative Committee on Standards on March 28, 1952. The following replace those formerly issued:

Designation	*Tentative Specifications for:*	Date
EA - A 199a	A 199 - 51 T	March 28, 1952
EA - A 200a	A 200 - 51 T	March 28, 1952
EA - A 213a	A 213 - 51 T	March 28, 1952

These emergency provisions have been published in the ASTM BULLETIN and have also been issued in the form of pink slips for attachment to the standards to which they apply.

On September 12, 1951, the Administrative Committee on Standards accepted the following recommendations submitted by Committee A-1:

Revision of Tentative Specifications for:

Welded and Seamless Steel Pipe (A 53 - 51 T),
Seamless Alloy Steel Boiler and Superheater Tubes (A 213 - 51 T),
Alloy-Steel Rounds Suitable for Oil Quenching to End-Quench Hardenability Requirements (A 304 - 47 T), and
Quenched and Tempered Steel Bolts and Studs with Suitable Nuts and Plain Washers (A 325 - 49 T).

Revision and Reversion to Tentative of Standard Specifications for:

Structural Nickel Steel (A 8 - 46),
Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 - 42),
Electric-Fusion-Welded Steel Pipe (Sizes 4 in. to but not including 30 in.) (A 139 - 46),
Welded Alloy-Steel Boiler and Superheater Tubes (A 249 - 47), and
Welded Alloyed Open-Hearth Iron Pipe (A 253 - 47).

These revised tentatives appear in the 1951 Supplement to Book of ASTM Standards, Part 1.

On October 29, 1951, the Administrative Committee accepted the following recommendations:

Revision of Tentative Specifications for:

Seamless and Welded Austenitic Steel Pipe (A 312 - 51 T).

Tentative Revision of Standard Specifications for:

Seamless Austenitic Chromium-Nickel Steel Tubes for Refinery Service (A 271 - 47).

The revised tentative as well as the tentative revision appear in the 1951 Supplement to Book of ASTM Standards, Part 1.

On February 15, 1952, the Administrative Committee on Standards accepted the following recommendations:

New Tentative Specifications for:

Forged or Rolled Carbon and Alloy Steel Flanges, Forged Fittings, and Valves and Parts for Low Temperature Service (A 350 - 52 T),

Ferritic and Austenitic Steel Castings for High Temperature Service (A 351 - 52 T), including withdrawal of the Tentative Specifications for Alloy-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 157 - 50 T),

Ferritic Steel Castings for Pressure Containing Parts Suitable for Low Temperature Service (A 352 - 52 T),

Low Carbon High Nickel Steel Plate for Pressure Vessels (A 353 - 52 T), and

Quenched and Tempered Alloy Steel Bolts and Studs with Suitable Nuts (A 354 - 52 T).

Revision of Tentative Specifications for:

General Requirements for Delivery of Rolled Steel Plates, Shapes, and Bars for Structural Use and Sheet Piling (A 6 - 51 T),

Structural Nickel Steel (A 8 - 51 T),

General Requirements for Delivery of Rolled Steel Plates of Flange and Firebox Qualities (A 20 - 50 T),

Boiler and Firebox Steel for Locomotives (A 30 - 50 T),

Boiler Rivet Steel and Rivets (A 31 - 51 T),

Welded and Seamless Steel Pipe (A 53 - 51 T),

Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 51 T),

Hot-Rolled Carbon-Steel Bars (A 107 - 50 T),

Seamless Alloy-Steel Pipe for High-Temperature Service (A 158 - 51 T),

Forged or Rolled Alloy Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 - 49 T),

Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 50 T),

Chromium-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 50 T),

Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 - 51 T),

Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 50 T),

Seamless Carbon-Molybdenum Alloy-Steel Pipe for High-Temperature Service (A 206 - 51 T),

High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 - 50 T),

Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 50 T),

Factory Made Wrought Carbon Steel and Ferritic Alloy Steel Welding Fittings (A 234 - 51 T),

Seamless Chromium-Molybdenum Alloy-Steel Pipe for Service at High Temperatures (A 280 - 51 T),

Low and Intermediate Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (Plates 2 in. and Under in Thickness) (A 285 - 50 T),

Heat-Treated Alloy-Steel Bars (A 286 - 50 T),

Alloy Steel Forgings for Nonmagnetic Coil Retaining Rings for Turbine Generators (A 289 - 49 T),

Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 50 T),

Carbon and Alloy Steel Forgings for Turbine Bucket Wheels (A 294 - 50 T),

High Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 299 - 50 T),

Steel Plates for Pressure Vessels for Service at Low Temperatures (A 300 - 50 T),

Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 - 51 T),

Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 - 50 T),

Alloy-Steel Rounds Suitable for Oil Quenching to End-Quench Hardenability Requirements (A 304 - 51 T),

Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 - 50 T),

Seamless 1 Per Cent Chromium, 0.5 Per Cent Molybdenum Alloy-Steel Pipe for Service at High Temperatures (A 315 - 51 T),

Heat-Treated Carbon-Steel Bars (A 321 - 50 T),

Hot Rolled Alloy Steel Bars (A 322 - 51 T), and

Seamless Ferritic Alloy Steel Pipe for High Temperature Service (A 335 - 51 T).

Revision and Reversion to Tentative of Standard Specifications for:

Electric-Fusion-Welded Steel Pipe for High Temperature and High Pressure Service (A 155 - 51).

The new and revised tentatives have been published in separate form and those covering piping materials appear in the special compilation "ASTM Specifications for Steel Piping Materials," February, 1952.

RECOMMENDATIONS AFFECTING STANDARDS

Committee A-1 is presenting for publication 5 new tentatives and is recommending the revision of 33 tentatives, the adoption as standard of one tentative, and revisions in 2 standards for immediate adoption. Editorial revisions in 13 specifications are also being recommended.

The standards and tentatives affected, together with the revisions recommended are given in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Several of the most significant subcommittee activities have already been mentioned in the beginning of the report. Over-all activity is too broad for mentioning every separate item under discussion, but some of the most important follow.

Subcommittees II and XI are reviewing the elongation modification clauses for 2-in. gage length specimens in the structural steel and boiler plate specifications with a view towards bringing the modifications into line with the recently adopted minimum values used in place of sliding scale figures. Two boiler plate specifications for (*1*) 2¼ per cent chromium, 1 per cent molybdenum and (*2*) carbon steel plates suitable for resisting graphitization at 900 F are being considered.

Specifications for forgings suitable for light weight pressure vessels and methods for mechanical testing of forgings are in final stages in Subcommittee VI. The revisions in Specifications A 273 and A 274 covering blooms, billets, and slabs for forgings are still being discussed in Committee A-1.

In the field of bar steels proposed specifications for cold finished heat treated alloy steel bars are approaching final form. Emergency alternate provisions for boron steels and other emergency grades for the standard alloy analyses in the bar steel specifications are expected to be submitted to the Society for publication before the Annual Meeting.

Last year Committee A-1 appended to its preprinted report proposed Tentative Specifications for Carbon Steel Sheets of Flange and Firebox Qualities but then withdrew the recommendation at the Annual Meeting. The method of sampling for this material has been under discussion since that time, and it is hoped that the problem will soon be resolved. The sampling is complicated by the fact that the product, due to present equipment, must be produced in coils and then cut to length, and also due to the fact that tensile samples may represent a relatively large number of samples.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, N. L. Mochel.

Vice-Chairmen, H. B. Oatley, T. G. Stitt.

Secretary, J. S. Worth.

This report has been submitted to letter ballot of the committee, which consists of 280 members; 205 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

N. L. MOCHEL,
Chairman.

J. S. WORTH,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the letter ballot are on record at ASTM Headquarters.

EDITORIAL NOTE

On June 13, 1952, the Administrative Committee on Standards accepted the recommendation of Committee A-1 that the Tentative Method of Macroetch Testing and Inspection of Steel Forgings (A 317 - 48 T) be revised. The revised method appears in the 1952 Book of ASTM Standards, Part 1.

Subsequent to the Annual Meeting, Committee A-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Steel for Bridges and Buildings (A 7 - 52 T),
Structural Nickel Steel (A 8 - 52 T),
Boiler and Firebox Steel for Locomotives (A 30 - 52 T),
Structural Silicon Steel (A 94 - 52 T),
Structural Steel for Locomotives and Cars (A 113 - 52 T),
Open-Hearth Iron Plates of Flange Quality (A 129 - 50 T),
Structural Steel for Ships (A 131 - 52 T),
Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 52 T),
Chromium-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 52 T),
Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 - 52 T),
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 52 T),
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 - 52 T),
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 52 T),
Low-Alloy Structural Steel (A 242 - 50 T),
Carbon-Steel Blooms, Billets, and Slabs for Forgings (A 273 - 47 T),
Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 274 - 44 T),
Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness) (A 283 - 52 T),
Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates of Structural Quality (A 284 - 52 T),
Low and Intermediate Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (Plates 2 in. and Under in Thickness) (A 285 - 52 T),
High Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 299 - 52 T),
Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 - 52 T),
Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 - 52 T), and
Quenched and Tempered Steel Bolts and Studs with Suitable Nuts and Plain Washers (A 325 - 51 T).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the revised tentative specifications appear in the 1952 Book of ASTM Standards, Part 1.

The following recommendations submitted by Committee A-1 were accepted by the Administrative Committee on Standards on October 21, 1952:

Tentative Specifications for:

Cold Finished Heat Treated Alloy Steel Bars (A 364 - 52 T).

Revision of Tentative Specifications for:

General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use (A 6 - 52 T),
Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 - 51 T),
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 - 52 T),
Alloy-Steel Bolting Materials for High-Temperature Service (A 193 - 51 T),
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 51 T),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 51 T),
Seamless Alloy-Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 - 52 T),
Factory-Made Wrought Carbon Steel and Ferritic Alloy-Steel Welding Fittings (A 234 - 52 T),
Alloy-Steel Bars to End-Quench Hardenability Requirements (A 304 - 52 T),
Alloy-Steel Bolting Materials for Low-Temperature Service (A 320 - 51 T),
Seamless Ferritic Alloy Steel Pipe for High-Temperature Service (A 335 - 52 T), and
Alloy Steel Bars for Nitriding (A 355 - 52 T).

Tentative Revision of Standard Specifications for:

Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 105 - 46), and
Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for General Service (A 181 - 49).

Withdrawal of Tentative Specifications for:

Seamless Alloy-Steel Pipe for High-Temperature Service (A 158 – 52 T),
Seamless Carbon-Molybdenum Alloy-Steel Pipe for High-Temperature Service (A 206 – 52 T),
Seamless Chromium-Molybdenum Alloy-Steel Pipe for Service at High Temperatures (A 280 – 52 T), and
Seamless 1 Per Cent Chromium, 0.5 Per Cent Molybdenum Alloy-Steel Pipe for Service at High Temperatures (A 315 – 52 T).

The new and revised tentative specifications and tentative revisions of the standard specifications appear in the 1952 Book of ASTM Standards, Part 1.

On December 12, 1952, the Standards Committee approved revisions in the following specifications which appear in the 1952 Book of ASTM Standards, Part 1:

Revision of Tentative Specifications for:

Billet-Steel Bars for Concrete Reinforcement (A 15 – 50 T),
Rail-Steel Bars for Concrete Reinforcement (A 16 – 50 T), and
Axle-Steel Bars for Concrete Reinforcement (A 160 – 50 T).

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON STEEL

In this Appendix recommendations are given affecting certain specifications, both standard and tentative, covering various steel products. These specifications appear in their present form in either the 1949 Book of ASTM Standards, Part 1, or in the 1950 or 1951 Supplements, Part 1, as indicated by the final number in the ASTM designation. Those specifications with "52" designations have been issued as separate reprints.

NEW TENTATIVES

The committee recommends that the following five new tentatives, as appended hereto, be accepted for publication as tentative:

Tentative Methods and Definitions for the Mechanical Testing of Structural Steel:[1]

These methods have been developed as part of an over-all plan in Committee A-1 to furnish the steel industry, producers and consumers alike, with standardized procedures for testing steel products.

Tentative Specifications for Heavy Walled Carbon and Alloy Steel Castings for Steam Turbines:[1]

These specifications cover one carbon steel and nine alloy steels suitable for cylinders (shells), valve chests, throttle valves, and other heavy walled castings for steam turbines.

Tentative Specification for 5 Per Cent Chromium, 0.5 Per Cent Molybdenum Steel Plates for Boilers and Other Pressure Vessels:[1]

For some time a need has been evident for a specification covering this grade of material. The appended proposed specification is intended to fill this need.

Tentative Specification for Alloy Steel Bars for Nitriding:[1]

Under development for a number of years, this specification is intended to furnish an acceptable basis for the commercial purchasing of the product.

Tentative Specifications for Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steep Pipe for High Temperature Service:[1]

These specifications cover four grades of austenitic steel. It is intended as a companion to the Tentative Specifications for Electric-Fusion-Welded Steel Pipe for High Temperature and High Pressure Service (ASTM Designation: A 155).[2]

REVISIONS OF TENTATIVES

The committee recommends revisions in the following 33 tentatives:

Tentative Specification for General Requirements for Delivery of Rolled Steel Plates, Shapes, and Bars for Structural Uses and Sheet Piling (A 6 - 52 T):

Section 7.—Revise to read as follows:

7. (*a*) *Methods of Testing:* All tests shall be conducted in accordance with the Tentative Methods and Definitions for the Mechanical Testing of Structural Steel (A 359).[2]

(*b*) The yield point shall, as described in Methods A 359 be determined by (*1*) the drop of the beam or halt in the gage of the testing machine, or (*2*) by the commencement of visible elongation as indicated by the use of dividers; or

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[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

(*3*) by the stress-strain diagram where the unit stress at the top of the knee is interpreted as the yield point, or (*4*) by the total strain method where the unit stress at an extension of 0.005 in. per in. of gage length as measured by an extensometer may be accepted as the equivalent of drop of the beam or halt in the gage and reported as the yield point. This same value may be obtained from an autographic stress-strain recorder.

(*c*) From the start of loading the specimen, until a value estimated as one-half of the specified yield point is reached, any convenient speed of the crosshead of the testing machine may be used. When the value estimated as being one-half of the specified yield point is reached, the speed of the crosshead under load shall be adjusted so that its rate of travel will not exceed $\frac{1}{16}$ in. per min per in. of gage length. This speed shall be maintained through the yield point. In determining the ultimate tensile strength the crosshead speed under load shall not exceed $\frac{1}{2}$ in. per min per in. of gage length.

TABLE I.—PERMISSIBLE VARIATIONS IN LENGTH FOR HOT-CUT CARBON STEEL BARS.

Specified Size of Rounds, Squares and Hexagons, in.	Specified Size of Flats, in.		Permissible Variations Over Specified Length Given in Feet, in. (No Variation Under)				
	Thickness	Width	5 to 10, excl.	10 to 20, excl.	20 to 30, excl.	30 to 40, excl.	40 to 60, incl.
HOT SHEARING							
1 and under	1 and under	3 and under	½	¾	1¼	1¾	2¼
Over 1 to 2, incl.	Over 1	3 and under	⅝	1	1½	2	2½
Over 1 to 2, incl.	1 and under	Over 3 to 6, incl.	⅝	1	1½	2	2½
Over 2 to 5, incl.	Over 1	Over 3 to 6, incl.	1	1½	1¾	2¼	2¾
Over 5	...	...	2	2½	2¾	3	3¼
Other sections	...	...	⅝	1	1½	2	2½
HOT SAWING							
2 to 5, incl.[a]	1 and over	3 and over	[a]	1½	1¾	2¼	2¾
Over 5	...	...	[a]	2½	2¾	3	3¼

[a] Smaller sizes and shorter lengths are not commonly hot sawed.

Section 11 (*c*).—Revise to read "If the results on an original tensile specimen are within 2000 psi of the required tensile strength, within 1000 psi of the required yield point, or within 2 per cent of the required elongation, a retest shall be permitted, for which one random specimen from the heat or test lot shall be used. If the results on this retest specimen meet the specified requirements the heat or test lot will be accepted."

Table XXIV.—Revise to read as shown in the accompanying Table I.

Tentative Specification for Steel for Bridges and Buildings (A 7 – 50 T):

Section 7.—Delete Paragraph (*c*).

Reletter Paragraph (*d*) as (*c*) and revise to read "For material over $\frac{3}{4}$ in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in Paragraph (*a*) of 0.50 per cent shall be made for each increase of $\frac{1}{8}$ in. of the specified thickness or diameter above $\frac{3}{4}$ in. This deduction shall not exceed 3 per cent."

Reletter Paragraph (*e*) as (*d*) and revise the deduction from the percentage of elongation in 8 in. for material under $\frac{5}{16}$ in. in thickness or diameter from the present "2.00" to "1.25" per cent for each decrease of $\frac{1}{32}$ in. of the specified thickness or diameter below $\frac{5}{16}$ in.

Tentative Specification for Structural Nickel Steel (A 8 – 52 T):

Section 6.—Delete Paragraph (*b*) and revise Paragraph (*c*) as indicated above for Section 7 (*e*) in Tentative Specification A 7.

Tentative Specifications for Mild- to Medium-Strength Carbon-Steel Castings for General Application (A 27 – 50 T):

Section 7 (*b*).—Revise the table of un-specified alloying elements to read as follows:

Copper, max, per cent	0.30
Nickel, max, per cent	0.50
Molybdenum, max, per cent	0.20
Chromium, max, per cent	0.20[a]

[a] For each reduction of 0.01 per cent carbon under the maximum specified, an increase of 0.04 per cent chromium above the maximum specified will be permitted, but in no case will the chromium exceed 0.40 per cent. No change is recommended on the other chemistry or the carbon-manganese relationship.

Tentative Specification for Structural Silicon Steel (A 94 – 50 T):

Section 6.—Delete Paragraph (*b*) and revise Paragraphs (*c*) and (*d*) as indicated above for Section 7 (*d*) and (*e*) in Tentative Specification A 7.

Tentative Specifications for Hot-Rolled Carbon-Steel Bars (A 107 – 52 T):

Section 3.—Revise to read "The steel shall be made by the open-hearth, electric-furnace, or acid-bessemer process.

Section 5 (*a*).—Revise to read "An analysis of each heat of open-hearth or electric-furnace steel shall be made to . . ."

Section 6 (*b*).—Revise the first sentence to read "Analysis may be made by the purchaser from finished bars of special quality representing each heat of open-hearth or electric-furnace steel, and . . ."

Table I.—Change sub-titles "Open-Hearth Grades" and "Open-Hearth Free-Cutting Grades" to read "Open-Hearth and Electric-Furnace Grades" and "Open-Hearth and Electric-Furnace Free-Cutting Grades," respectively.

Add the following new grades to Table I:

Grade Designation	Carbon, max, per cent	Manganese, per cent	Phosphorus, per cent	Sulfur, per cent
1211......	0.13	0.60 to 0.90	0.07 to 0.12	0.08 to 0.15
1212......	0.13	0.70 to 1.00	0.07 to 0.12	0.16 to 0.23
1213......	0.13	0.70 to 1.00	0.07 to 0.12	0.24 to 0.33

Revise Footnote *a* to read as follows, retaining the present tabular material: "Silicon content can not be specified on any open-hearth or electric-furnace grades ordered as merchant quality. Silicon ranges as noted below may be specified for open-hearth or electric-furnace grades of special quality. . . ."

Revise Footnote *b* to read "Bessemer grades and grades 1109, 1110, 1211, 1212, and 1213 are not supplied with a specified silicon content."

Tentative Specifications for Cold-Finished Carbon-Steel Bars and Shafting (A 108 – 50 T):

Section 3.—Revise as indicated above for Section 3 in "Tentative Specifications A 107.

Table I.—Change sub-titles and add grades 1211, 1212, and 1213 as indicated above for Table I in Specifications A 107.

Revise Footnote *a* to read as follows, retaining the present tabular material: Silicon ranges as noted below may be specified for open-hearth or electric-furnace grades."

Revise Footnote *b* to read "Bessemer compositions and grades 1211, 1212, and 1213 are not supplied with a specified silicon content."

Tentative Specification for Structural Steel for Locomotives and Cars (A 113 – 50 T):

Section 6.—Delete Paragraph (*c*) and revise Paragraphs (*d*) and (*e*) as indicated above for Section 7 (*d*) and (*e*) in Tentative Specification A 7.

Tentative Specification for Structural Steel for Ships (A 131 – 50 aT):

Section 5.—Delete Paragraph (*c*) and revise Paragraphs (*d*) and (*e*) as indicated above for Section 7 (*d*) and (*e*) in Tentative Specification A 7.

Tentative Specification for Structural Rivet Steel (A 141 – 50 T):

Section 5.—Delete Paragraph (*b*).

Tentative Specifications for Electric-Fusion-Welded Steel Pipe for High Temperature and High Pressure Work (A 155 – 52 T):

Title.—Delete the words "and High Pressure."

Section 12.—Add the following sentence: "The hydrostatic test pressure shall be held for a sufficient length of time for the inspector to completely examine the entire length of the pipe and the welded joint."

Tentative Specification for High-Strength Structural Rivet Steel (A 195 50 T):

Section 6.—Delete Paragraph (*b*).

Tentative Specifications for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 – 51 T):

Section 3 (*b*).—Revise to read "Hot-finished tubes shall be annealed or normalized and drawn. Cold-drawn tubes shall be annealed after the final cold-draw pass."

Tentative Specifications for Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 – 51 T):

Section 9.—Revise the first two sentences of Paragraph (*c*) to read "Except for tubes fabricated from ferritic grade T13, the tubes fabricated from ferritic grades shall have a Brinell hardness not to exceed 163 (Rockwell B 85). For grade T13, the Brinell hardness shall not exceed 179 (Rockwell B 89)."

Section 18 (*c*).—Revise to read "The austenitic steel tubes shall be pickled free from scale."

Tentative Specification for Low-Alloy Structural Steel (A 242 – 50 T):

Section 6.—Delete Paragraph (*b*) and revise Paragraph (*d*) as indicated for Section 7 (*e*) in Tentative Specification A 7.

Tentative Specification for Carbon Steel Forgings for General Industrial Use (A 235 – 49 T):

Tentative Specification for Carbon Steel Forgings for Locomotives and Cars (A 236 – 49 T):

Tentative Specification for Alloy Steel Forgings for General Industrial Use (A 237 – 49 T):

Table III.—Add the following Footnote *a* to this table, referenced after "Bored Wall Thickness, in.," relettering the other footnotes accordingly: "Where no figures are shown in the bored wall thickness column it is understood that the size classification is determined by the outside diameter, whether the forging is bored or not."

Tentative Specifications for Heavy Gage Structural Quality Flat Hot-Rolled Carbon-Steel Sheets (A 245 – 48 T):

Tentative Specifications for Light Gage Structural Quality Flat Rolled Carbon-Steel Sheets (A 246 – 48 T):

Section 3.—Revise to read "The steel shall be made by any of the following processes: open-hearth, electric-furnace, or acid-bessemer."

Section 4.—In the table of chemical requirements revise the heading "Open-Hearth" to read "Open-Hearth and Electric-Furnace."

Section 5.—Revise the first sentence to read "For all grades, an analysis of each heat of open-hearth or electric-furnace steel shall be. . . ."

Section 12.—Revise the second sentence to read "Material of grades A, B, and C shall be identified by having the grade designation and the heat number of open-hearth or electric-furnace steel or the. . . ."

Section 13.—Revise to read as follows:

13. The surface of cut lengths shall be free from injurious imperfections consistent with the surface finish specified. Coils may contain some

abnormal imperfections such as welds to join coils, holes, etc., which render a portion of the coil unusable, since the inspection of coils does not afford the same opportunity to reject portions containing imperfections as is the case with cut lengths. However an excessive number of abnormal imperfections is cause for rejection.

Section 15.—Revise to read as follows by the addition of the italicized words: "Material that shows injurious imperfections subsequent to its acceptance at the manufacturer's works, *except as noted in Section 13,* will be rejected and the manufacturer shall be notified."

Tentative Specifications for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger, and Condenser Tubes (A 249 – 51 T):

Section 20 (b).—Revise to read as indicated above for Section 18 (*c*) in Tentative Specifications A 213.

Tentative Specification for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness) (A 283 – 50 T):

Section 5.—Delete Paragraph (*b*) and revise Paragraphs (*c*) and (*d*) as indicated above for Section 7 (*d*) and (*e*) in Tentative Specification A 7.

Tentative Specification for Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates for Machine Parts and General Construction (A 284 – 51 T):

Section 6.—Delete Paragraph (*b*) and revise Paragraphs (*c*) and (*d*) as indicated above for Section 7 (*d*) and (*e*) in Tentative Specification A 7.

Tentative Specification for Carbon Steel Forgings for Rings for Main Reduction Gears (A 290 – 49 T):

Expanded to cover nine classes of carbon and alloy steel forgings, the proposed revised specification is appended hereto.[4]

Tentative Specification for Carbon and Alloy Steel Forgings for Pinions for Main Reduction Gears (A 291 – 49 T):

Section 1.—Revise to read as follows:

1. (*a*) This specification covers normalized and tempered carbon steel (class 1) and alloy steel (classes 2 and 3) and quenched and tempered alloy steel (classes 4 to 8) forgings for pinions for reduction gears.

(*b*) Supplementary requirements (Paragraphs S1 to S3) of an optional nature are provided. These shall apply only when specified by the purchaser.

Section 5.—In Paragraph (*b*), first sentence, delete the words "in accordance with Supplementary Requirement S1."

Section 6.—Revise to read as follows:

6. At the option of the manufacturer, forgings may either be given such preliminary heat treatment as is necessary to make them machinable, then machined, and then heat treated as required in Section 7; or they may be heat treated as required by Section 7 after forging prior to any machining.

Section 7 (a).—Revise to read as follows:

(*a*) The heat treatment for classes 1 to 3 inclusive, shall consist of normalizing and tempering, or, where agreed upon by the manufacturer and the purchaser in accordance with Supplementary Requirement S1, quenching and tempering, also stress relieving when required in accordance with Section 6. For classes 4 to 8, inclusive, the heat treatment shall consist of quenching in a suitable medium and tempering, also stress relieving when required in accordance with Section 6.

Section 8 (a).—Add the following sentence: "Other compositions may be agreed upon by the manufacturer and the purchaser."

Table I.—Revise to read as shown in the accompanying Table II.

Table II.—Revise to read as shown in the accompanying Table III.

Table III.—Add tensile requirements

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[4] The revised specification was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 1.

TABLE II.—CHEMICAL REQUIREMENTS.

	Class 1	Class 2	Class 3	Classes 4 to 7	Class 8
Carbon, min, per cent	0.40	...	0.45 max	0.35 to 0.45	0.40 to 0.55
Manganese, min, per cent	0.55	...	...	...	...
Phosphorus, max, per cent	0.050	0.050	0.050	0.050	0.050
Sulfur, max, per cent	0.050	0.050	0.050	0.050	0.050
Silicon, min, per cent	0.15	...	0.15	0.15	0.15
Nickel, per cent	...	...	3.00 max	1.65 min	1.65 min
Chromium, per cent	...	...	1.25 max	0.60 min	0.60 min
Molybdenum, min, per cent	...	...	0.15	0.20	0.20
Vanadium, max, per cent	...	...	0.10	0.10	0.10

TABLE III.—PERMISSIBLE VARIATIONS IN CHECK ANALYSIS.

Element	Permissible Variations Over the Maximum or Under the Minimum Limit, per cent				
	200 sq. in. and Under[a]	Over 200 to 400 sq. in., incl.[a]	Over 400 to 800 sq. in., incl.[a]	Over 800 to 1600 sq. in., incl.[a]	Over 1600 sq. in.[a]
Carbon	0.03	0.04	0.05	0.06	0.07
Manganese	0.04	0.05	0.06	0.07	0.08
Phosphorus	0.010	0.010	0.010	0.015	0.015
Sulfur	0.010	0.010	0.010	0.015	0.015
Silicon	0.02	0.03	0.04	0.04	0.05
Nickel	0.07	0.07	0.07	0.07	0.07
Chromium[b]	0.06	0.06	0.07	0.07	0.08
Chromium[c]	0.04	0.04	0.05	0.05	0.06
Molybdenum	0.04	0.05	0.06	0.07	0.08
Vanadium	0.01	0.01	0.01	0.02	0.02

[a] The significant cross-section of the forging shall be governed by the main body diameter.

[b] For class 3.

[c] For classes 4 to 8, incl.

for classes 3 to 8 as shown in the accompanying Table IV.

Table IV.—Add Brinell hardness requirements to cover all sizes of classes 3 to 8 as follows:

Class	Brinell Hardness Number
3	223 to 262
4	248 to 293
5	285 to 331
6	302 to 352
7	341 to 388
8	388 to 429

Section 14 (a).—Revise the first sentence to read "One tension test specimen, either longitudinal or transverse, at the option of the manufacturer or unless otherwise specified, shall be. . . ."

TABLE IV.—TENSILE REQUIREMENTS.

Class	Size, Solid Diameter or Thickness, in.		Tensile Strength, min, psi	Yield Point, min, psi	Elongation in 2 in., min, per cent		Reduction of Area, min, per cent	
	Over	Not Over			Longitudinal	Transverse	Longitudinal	Transverse
3	...	10	105 000	80 000	19	...	45	...
	10	20	105 000	80 000	19	16	45	30
	20	...	105 000	80 000	17	14	35	28
4	...	10	125 000	100 000	16	...	40	...
	10	20	125 000	100 000	14	12	35	30
	20	...	125 000	100 000	12	10	30	25
5	...	10	140 000	115 000	16	...	40	...
	10	20	140 000	115 000	14	12	35	30
	20	...	140 000	115 000	12	10	30	25
6	...	10	145 000	120 000	15	...	40	...
	10	20	145 000	120 000	14	12	35	30
	20	...	145 000	120 000	12	10	30	25
7	...	10	165 000	135 000	12	10	35	25
8	...	10	185 000	160 000	8	7	35	20

Section 15 (a).—Delete the words "but not more than three additional times."

New Section.—Add a new Section 22 to read as follows:

22. *Reports.*—The manufacturer shall furnish reports of the chemical analysis, mechanical test, and tempering temperature.

Supplementary Requirements S1.—Revise to read "Quenching and tempering of classes 1, 2, and 3 shall be. . . ."

New Supplementary Requirement.—Add a new Supplementary Requirement S3 titled "Special Procedure" to read: "Upon agreement between the manufacturer and the purchaser any class may be purchased in the annealed or normalized and tempered condition for subsequent treatment, the details of subsequent machining and treatments to be agreed upon."

Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 52 T):

Table I.—Add Footnote *a* to Table I to read "For classes 1 and 2 the minimum vanadium content requirement is optional."

Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts (A 293 - 50 T):

Table I.—Revise to read as shown in the accompanying Table V.

Section 8.—Delete Paragraph (*b*).

Table II.—Revise to read as shown in the accompanying Table VI.

Table III.—Revise the requirements for classes 5 and 6 and add requirements for new class 7 as shown in the accompanying Table VII.

Section 14 (a).—After the words "but not more than three additional times" add "without the approval of the purchaser."

Supplementary Requirement S5.—Revise to read "Where forgings of classes 1 and 2a for rotors are. . . ."

Tentative Specifications for Hot-Rolled Carbon-Steel Strip of Structural Quality (A 303 - 48 T):

Sections 2, 3, 4, 12, and 14.—Revise as indicated above for Sections 3, 4, 5, 13, and 15, respectively, in Tentative Specifications A 245.

Tentative Specifications for Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 - 52 T):

Section 11.—Replace the present Paragraph (*a*) by the following Paragraphs (*a*) and (*b*), relettering subsequent paragraphs accordingly.

11. (*a*) Two tension tests shall be made from each heat, unless the finished material from a heat is less than 30 tons when one tension test will be sufficient. If, however, material from one heat differs $\frac{3}{8}$ in. or more in thickness, one tension test shall be made from both the thickest and the thinnest material (larger than the sizes enumerated in Section 7 (*c*)), regardless of weight represented.

(*b*) Shapes less than 1 sq. in. in cross-section, and bars, (other than flats) less than $\frac{1}{2}$ in. in thickness or diameter shall be subject to bend tests. All other finished material shall be subject to bend tests only when specified by the purchaser. When subject to bend test, two bend tests shall be made from each heat unless the finished material from a heat is less than 30 tons when one bend test will be sufficient. If, however, material from one heat differs $\frac{3}{8}$ in. or more in thickness, one bend test shall be made from the thickest and the thinnest material rolled, regardless of weight represented. (Note: Bend tests should be specified by the purchaser only when the material is to be bent cold during fabrication).

Tentative Specifications for Steel Machine Bolts and Nuts and Tap Bolts (A 307 - 50 T):

Section 12.—Replace Paragraphs (*c*) and (*d*) with the following Paragraph (*c*):

(*c*) Nuts shall be in accordance with the American Standard for Square and Hexagon

TABLE V.—CHEMICAL REQUIREMENTS.

	Class 1	Class 2[a]	Class 2a[a]	Class 3	Class 4	Class 5	Class 6	Class 7
Carbon, max, per cent	0.50	0.35	0.35	0.35	0.35	0.40	0.40	0.40
Manganese, max, per cent	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Phosphorus, max, per cent	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Sulfur, max, per cent	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Silicon, per cent	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35
Nickel, per cent	...	1.75 min	2.75 min	1.75 min	2.25 min	2.50 min	2.50 min	2.50 max
Chromium, per cent	...	0.50 max	0.50 max	0.50 max	0.50 max	0.50 max	0.50 max	0.85 to 1.25
Molybdenum, per cent	...	0.45 to 0.65	...	0.45 to 0.65	0.45 to 0.65	0.45 to 0.65	0.45 to 0.65	0.50 to 1.50
Vanadium, per cent	0.03 min[b]	0.03 min	0.03 min	0.03 min	0.03 min	0.03 min	0.03 min	0.20 to 0.30

[a] Class 2a is an alternate for class 2, unless molybdenum is specified on the purchase order.

[b] Optional.

NOTE.—The above limits apply to forgings over 30 in. in diameter. For smaller forgings the limits for alloys may be owered by agreement between the manufacturer and the purchaser.

TABLE VI.—PERMISSIBLE VARIATIONS IN CHECK ANALYSIS.

Element	Permissible Variations Over the Maximum or Under the Minimum Limit, per cent				
	200 sq. in. and Under[a]	Over 200 to 400 sq. in., incl.[a]	Over 400 to 800 sq. in., incl.[a]	Over 800 to 1600 sq. in., incl.[a]	Over 1600 sq. in.[a]
Carbon	0.03	0.04	0.05	0.06	0.07
Manganese	0.04	0.05	0.06	0.07	0.08
Phosphorus	0.010	0.010	0.010	0.015	0.015
Sulfur	0.010	0.010	0.010	0.015	0.015
Silicon	0.02	0.03	0.04	0.04	0.05
Nickel	0.07	0.07	0.07	0.07	0.07
Chromium[b]	0.04	0.04	0.05	0.05	0.06
Chromium[c]	0.06	0.06	0.07	0.07	0.08
Molybdenum[b]	0.04	0.05	0.06	0.07	0.08
Molybdenum[c]	0.05	0.06	0.07	0.08	0.09
Vanadium[b]	0.01	0.01	0.01	0.02	0.02
Vanadium[c]	0.03	0.03	0.03	0.04	0.04

[a] The significant cross-section of the forging shall be governed by the main body diameter.

[b] For classes 1, 2, 2a, 3, 4, 5, and 6.

[c] For class 7.

Bolts and Nuts, Regular or Heavy Series (ASA No.: B18.2-1952). Unless otherwise specified, nuts for grade A bolts shall be the square Regular Series, and nuts for grade B bolts shall be the hexagon Heavy Series.

Tentative Specifications for Stress-Relief-Annealed Cold-Drawn Carbon-Steel Bars (A 311 – 49 T):

Section 3.—Revise to read "The steel shall be made by the open-hearth or electric-furnace process."

Tentative Specification for Steel Sheet Piling (A 328 – 50 T):

Section 6.—Delete Paragraph (*c*).

Tentative Specifications for Seamless Ferritic Alloy Steel Pipe for High Temperature Service (A 335 – 52 T):

Section 11 (*a*).—Change the requirement for hydrostatic test pressure from the present "0.50" to "0.60" times the minimum specified yield point at room temperature.

TABLE VII.—TENSILE REQUIREMENTS.

Class	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 2 in., min, per cent				Reduction of Area, min, per cent			
			Longitudinal Prolongation	Radial Body	Tangential Body		Longitudinal Prolongation	Radial Body	Tangential Body	
					Greater Than One-Half of Radius at Ends of Body	One-Half or Less of Radius at Ends of Body			Greater Than One-Half of Radius at Ends of Body	One-Half or Less of Radius at Ends of Body
5	100 000	75 000	20	16	16	16	40	27	27	27
6	105 000	85 000	17	14	14	14	37	24	24	24
7	125 000	95 000	16	12	12	12	35	22	22	22

ADOPTION OF TENTATIVE AS STANDARD

Tentative Specifications for Heat-Treated Steel Helical Springs (A 125 – 50 T):

The committee recommends that these specifications be approved for reference to letter ballot of the Society for adoption as standard.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in two specifications as indicated below and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 47):

Section 14 (*b*).—Revise to read as indicated above for Section 18 (*c*) in Tentative Specifications A 213.

Standard Specifications for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 47):

Section 16 (*b*).—Revise to read as indicated above for Section 18 (*c*) in Tentative Specifications A 213.

EDITORIAL CHANGES

The committee recommends editorial changes in the following 13 specifications:

Tentative Specifications for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 51 T):

Tentative Specifications for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 51 T):

Tentative Specifications for Seamless Alloy-Steel Boiler, Superheater and Heat Exchanger Tubes (A 213 – 51 T):

Tentative Specifications for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 – 51 T):

Table I.—In the above four specifications, change the chemical requirements for phosphorus and sulfur so that they are expressed to three decimal places.

Tentative Specifications for Hot-Rolled Carbon-Steel Bars (A 107 – 52 T):

Tentative Specifications for Cold-Finished Carbon-Steel Bars and Shafting (A 108 – 50 T):

Tentative Specifications for Heat-Treated Alloy-Steel Bars (A 286 – 52 T):

Tentative Specifications for Alloy-Steel Bars to End-Quench Hardenability Requirements (A 304 – 52 T):

Tentative Specifications for Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 – 52 T):

Tentative Specifications for Stress-Relief-Annealed Cold-Drawn Carbon-Steel Bars (A 311 – 49 T):

Tentative Specifications for Heat-Treated Carbon-Steel Bars (A 321 – 52 T):

Tentative Specifications for Hot-Rolled Alloy-Steel Bars (A 322 – 52 T):

Tentative Specifications for Cold-Finished Alloy-Steel Bars (A 331 – 52 T):

In the title and throughout the text of the above nine specifications, change the plural "specifications" to the singular "specification."

REPORT OF COMMITTEE A-2

ON

WROUGHT IRON*

Committee A-2 on Wrought Iron has been inactive for many years. Its reactivation is the result of certain activities in the wrought iron field, brought about by the obvious necessity of a ferrous corrosion-resisting metal in the field of metallurgy.

Just prior to the 1951 Annual Meeting, a steering committee consisting of D. M. Stembel, Vice President, Lockhart Iron and Steel Co., Pittsburgh, Pa.; L. S. Crane, Test Department, Southern Railway System, Alexandria, Va.; and A. D. Morris, President, Bayonne Bolt Corp., New York, N. Y., met in Pittsburgh with the thought that the reactivation of Committee A-2 could be effected.

A meeting was held in Atlantic City during the 1951 Annual Meeting with an attendance of about 16 men, all interested in wrought iron for various purposes and kinds. In this group were represented two manufacturers of the basic product, six in the consuming field such as railroads, industries, etc., four in the general interest of the public, and the U. S. Government was represented through the Office of Chief of Ordnance. At this meeting the committee commenced to function with A. D. Morris, Bayonne Bolt Corp., as chairman; D. M. Stembel, Lockhart Iron and Steel Co., vice-chairman; and L. S. Crane as secretary.

In the procedure of reactivation, the following subcommittees were appointed and chairmen selected:

Subcommittee I. Tubes and Pipe
Subcommittee II. Bars, Blooms, and Forgings
Subcommittee III. Plates, Shapes, and Sheets
Subcommittee IV. Chain Iron and Iron Chain
Subcommittee V. Nomenclature and Definitions
Subcommittee VI. Research

These subcommittees are now beginning to function. Letter ballots were issued and received with no negative votes on the deletion of the requirements for wrought iron from the Standard Specifications for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (ASTM Designation: A 83).[1] This action, which was approved by the Administrative Committee on Standards on May 14, 1952, carried with it the transfer to Committee A-1 of sole jurisdiction of these specifications which were formerly under the joint jurisdiction of Committees A-1 and A-2. Such tubes are no longer made of wrought iron and have reverted entirely to steel.

Discussions were held during the current year on the question of further withdrawal of specifications, with the indication that these matters would be carried over to the 1952 meeting for further action. Committee A-2 did not participate in any formal meeting during the period between the Atlantic City, N. J., meeting at which it was reactivated, and the 1952 Annual Meeting, where plans have been set up for a complete meeting with three subcommittee meetings functioning.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 1.

The opinion has been formed that Committee A-2 can function just so long as wrought iron is produced in this country, and just so long as there is a consumer demand for the product. As time goes on, the wisdom of reactivating Committee A-2 as a growing member of the ASTM family should prove a worthwhile project.

Respectfully submitted on behalf of the committee,

A. D. MORRIS,
Chairman.

L. S. CRANE,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision and Reversion to Tentative of Standard Specifications for:

Wrought Iron Plates (A 42 - 47),
Welded Wrought Iron Pipe (A 72 - 46),
Staybolt Wrought Iron, Solid (A 84 - 39), and
Staybolt Wrought Iron, Hollow-Rolled. (A 86 - 39).

Withdrawal of Standard Specifications for:

Common Iron Bars (A 85 - 36).

These recommendations were accepted by the Standards Committee on December 12, 1952, and the revised specifications appear in the 1952 Book of ASTM Standards, Part 1.

REPORT OF COMMITTEE A-3
ON
CAST IRON*

The most important action of Committee A-3 during the past year was the development of Specifications for Nodular Iron Castings. The specifications were presented to the Society through the Administrative Committee on Standards and approval of the specifications for publication as tentative was granted by the Standards Committee on November 27, 1951. The new tentative specifications appear in the 1951 Supplement to Book of ASTM Standards, Part 1, bearing the designation A 339 - 51 T.

The specifications were the result of very intensive study by Subcommittee XXIV under the chairmanship of T. E. Eagan.

It should also be reported that Hyman Bornstein, past chairman, was nominated by Committee A-3 for the ASTM Award of Merit and was awarded this honor at the 1951 Annual Meeting of the Society.

Personnel.—The officers are engaged in the review of the subcommittee chairmen, the results of which will be announced at the Annual Meeting.

There have been a few changes in personnel of Committee A-3. The committee at present consists of 119 voting members, of whom 40 are classified as producers, 49 as consumers, and 30 as general interest members.

The committee records with regret the death of two long-time members. Robert Job of the Milton Hersey Co., Ltd., an Honorary Member of ASTM, was a member of the Society since 1900. Charles Haydock, Consulting Engineer, was a member of the Society since 1927.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. S. Vanick.
Vice-Chairman, C. O. Burgess.
Secretary, D. E. Krause.

NEW TENTATIVE

The committee recommends that the Tentative Specifications for Chilled and White Iron Castings as appended[1] to this report be accepted for publication as tentative

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

REAFFIRMATION OF STANDARDS

The committee recommends that the following ten standards be reaffirmed and continued as standard without change:

Standard Specifications for:

Cast Iron Pit-Cast Pipe for Water or Other Liquids (A 44 - 41),
Gray Iron Castings (A 48 - 48),
Cast Iron Soil Pipe and Fittings (A 74 - 42),
Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A 126 - 42),
Cast Iron Culvert Pipe (A 142 - 38), and
Lightweight and Thin-Sectioned Gray Iron Castings (A 190 - 47).

Standard Method of:

Compression Testing of Cast Iron (A 256 - 46).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 1.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Definitions of Terms:

Relating to Cast Iron (A 196 – 47).

Recommended Practices for:

Evaluating the Microstructure of Graphite in Gray Iron (A 247 – 47), and
Torsion Tests of Cast Iron (A 260 – 47).

TENTATIVES CONTINUED WITHOUT REVISION

The following four tentatives have been published for two years or more without change, and the committee recommends their continuation as tentative without revision at this time:

Tentative Specifications for:

Foundry Pig Iron (A 43 – 49 T),
Automotive Gray Iron Castings (A 159 – 49 T), and
Gray Iron Castings for Elevated Temperature for Non-Pressure Containing Parts (A 319 – 48 T).

Tentative Method of:

Impact Testing of Cast Iron (A 327 – 50 T).

This report has been submitted to letter ballot of the committee which consists of 119 members; 82 members returned their ballots, of whom 80 have voted affirmatively and 0 negatively.

Respectively submitted on behalf of the committee,

J. S. VANICK,
Chairman

H. W. STUART,
Secretary.

REPORT OF COMMITTEE A-5
ON
CORROSION OF IRON AND STEEL*

Committee A-5 on Corrosion of Iron and Steel held meetings on June 20, 1951 at Atlantic City, N. J. and on March 4, 1952 at Cleveland, Ohio. The committee now consists of 113 members, of whom 49 are classified as producers, 34 as consumers, and 30 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. P. Jahn.
Vice-Chairman, J. G. Thompson.
Secretary, C. P. Larrabee.

NEW TENTATIVE

Committee A-5 recommends for publication as tentative the proposed Tentative Specifications for 1.25 oz Ordered Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets as appended hereto.[1]

REVISION OF TENTATIVE

The committee recommends the revision of Tentative Specifications for Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 - 50 T).[2] The objects of the revision are: to expand the bend test table to include gages heavier than 16 G.S.G., to delete all reference to sheet weight tests, and to clarify the term "Ordered Coating" by adding the term "Pot Yield." The above revisions cause changes in Sections 6, 8, and 11 which are incorporated in A 93 as it appears in Part 1 of the 1952 Book of ASTM Standards.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends the adoption as standard of Tentative Specifications for Zinc-Coated (Galvanized) High-Tensile Steel Telephone and Telegraph Line Wire (A 326 - 49 T)[3] with the following revision and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

Section 14 (*c*).—Revise to read as follows:

> (*c*) Each coil shall be securely bound in four separate places, equally spaced, with at least two wrappings of galvanized wire not smaller than 0.080 in. in diameter. As an alternative, coils of 83 lb nominal weight may be securely bound in three separate places, equally spaced, with a zinc-coated steel strap not less than ½ in. wide by 0.020 in. thick. The outer end of each coil shall be bent back over the binding wire or strap to prevent it from crowding into the coil.

REVISION OF STANDARD

The committee recommends that the Standard Specifications for Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Wire (A 111 - 51)[3] be revised as indicated, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 1.

[2] 1950 Supplement to Book of ASTM Standards, Part 1.

[3] 1949 Book of ASTM Standards, Part I.

Section 14 (*c*).—Revise to read as follows:

> (*c*) Each coil shall be securely bound in four separate places, equally spaced, with at least two wrappings of galvanized wire not smaller than 0.080 in. in diameter. As an alternative, coils of 83 lb nominal weight may be securely bound in three separate places, equally spaced, with a zinc-coated steel strap not less than ½ in. wide by 0.020 in. thick. The outer end of each coil shall be bent back over the binding wire or strap to prevent it from crowding into the coil.

REAFFIRMATION OF STANDARDS

The committee recommends the reaffirmation of the following four specifications, two methods of test, and one recommended practice without change.

Standard Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 – 33),[3]

Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized After Weaving (A 117 – 33),[3]

Zinc Coated Steel Wire Strand ("Galvanized" and Class A) ("Extra Galvanized") (A 122 – 41),[3] and

Zinc Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 – 41).[3]

Methods of Test for:

Weight of Coating on Zinc Coated (Galvanized) Iron or Steel Articles (A 90 – 39),[3]

Uniformity of Coating by the Preece Test (Copper Sulphate Dip) on Zinc-Coated (Galvanized) Iron and Steel Articles (A 239 – 41).[3]

Recommended Practice for:

Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A 143 – 46).[3]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends the continuance of the following tentatives without change:

Tentative Specifications for:

Lead-Alloy Coating (Hot Dip) on Iron or Steel Hardware (A 267 – 46 T).[3] In recent years the committee recommended the retention of this specification as tentative because of uncertainty as to the need for the specification. A steady decline in the use of lead-coated hardware had taken place so that it appeared likely the eventual recommendation of the committee would be to drop the specification. However the shortage of metals has caused some renewal of interest in the use of lead-coated hardware, and the committee is therefore deferring the recommendation to drop this specification. Under the circumstances it seems best to retain it as a tentative specification.

Long Terne Iron or Steel Sheets, Coils and Cut Lengths (A 308 – 50 T).[2] Changes to this specification are being contemplated which may result in a revision within the near future and there is no point therefore in changing its status.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee VII on Methods of Test (W. E. Buck, chairman) has under consideration changes in Methods of Test for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 – 39) and Methods of Test for Weight and Composition of Coating on Long Terne Sheets by the Triple Spot Test (A 309 – 49), to allow sampling of material from which full sized samples, as now outlined, cannot be obtained. A subcommittee has been appointed to study the problem of determining the weight of coating on narrow strip. Progress is being made in the study of the behavior of various types of zinc coatings in copper sulfate solutions.

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[4] The letter ballot on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee XI on Sheet Specifications (E. F. Lundeen, chairman) is actively at work reviewing Specification A 93 – 50 T, covering Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths; and Specification A 308 – 50 T, covering Long Terne Iron or Steel Sheets, Coils and Cut Lengths. The inclusion of coils in these specifications causes certain complications in the present Finish and Inspection paragraphs, inasmuch as in the production of coils, it is sometimes not possible to produce a coil that is entirely free from injurious defects.

In Specification A 93 – 50 T, it is also proposed to expand Tables II and III to include all gage numbers. Provision is also being made for sampling of coils narrower than the 2.25-in. test samples.

Subcommittee XII on Wire Specifications (J. F. Occasione, chairman) recommended that Tentative Specifications for Zinc-Coated (Galvanized) High-Tensile Steel Telephone and Telegraph Line Wire (A 326 – 49 T) be adopted as standard which recommendation was approved by the main committee. A minor revision to provide for an alternate method of binding by use of steel straps was made. After due consideration, it was decided not to include the 190,000 psi tensile strength grade in this specification since the manufacture and use of this grade is still in the development stage. An amendment to two Specifications for Zinc-Coated Steel Wire Strand (A 122 – 41) and (A 218 – 41) which would eliminate the minimum length of pitch for seven wire strand and the outer layer of 19 and 37 wire strand is under consideration. This change is prompted by the fact that some manufacturers experienced difficulty in conforming to the minimum length of pitch when making preformed strand. A proposed tentative specification is being prepared for strand for use as Overhead Ground Wire. No welds made in the finished wire after drawing will be permitted in this strand. The standard Specification for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 – 33) is in process of revision. Changes to be incorporated are, deletion of uniformity of coating requirement by the preece test, addition of alternate packaging in fiber board or kraft tubes or corrugated fiber board boxes, and modification of sampling and rejection procedure.

Subcommittee XIII on Hardware Specifications (B. J. Barmack, chairman) is conducting a letter ballot on revisions of the Standard Specifications for Zinc (Hot-Galvanized) Coating on Structural Steel Shapes, Plates, and Bars, and Their Products (A 123 – 47) and Standard Specifications for Zinc Coating (Hot-Dip) on Iron and Steel Hardware (A 153 – 49). In A 123 – 47, it is proposed to modify the title and the scope to include strip and shapes which are not necessarily structural. The deletion of Section 3, Impurities, is suggested because the amount of impurities is stated in B 6 for the grade of zinc used. A new clause is proposed in Section 6, Weight of Coating, to specify galvanizing of bolts and fasteners in accordance with A 153, because tests indicated that coating weights for tower bolts are of the same order as for the bolts used in pole-line hardware. Another paragraph is proposed to show the thickness of zinc coating for 1 oz per sq ft of surface to facilitate calculations when non-destructive methods, such as magnetic gages, are used.

In A 153 – 49, it is proposed to increase the weight of coating for Class A, Castings, to 2.00 oz as the result of tests made on that type of material. Washers are to be placed into proper classes to eliminate unnecessary rejections in "borderline" cases. The proposed change in the Scope and Note 3 under Table I will provide for the inclusion of light steel shapes, such as used for window sash, in A 153, and the weight of coating can be obtained from Class B-2 or Class B-1 depending upon the thickness of the steel shapes. A note similar to the one in A 123 is to be added to aid in converting the thickness into the weight of coating per sq ft of surface.

An Appendix is to be added with statements of suggested procedures to check the embrittlement and malleability of steel used. Another note is to be added to indicate that the use of low-alloy steel for pole-line hardware will result in increased service life due to corrosion resistance of these steel and improved zinc coating weights, often well above the minimum values shown in Table I of these specifications.

Subcommittee XIV on Sheet Tests (E. S. Taylerson, chairman). The report of this subcommittee is appended hereto under the title "Report of Subcommittee XIV on Inspection of Black and Galvanized Sheets."

Subcommittee XV on Wire Tests (A. P. Jahn, chairman) has continued with the field inspections but has made no detailed report this year, the last such report having been made in 1951 which included the results of the 1950 inspection. A detailed report will be made in 1953 to include the results of the 1951 and 1952 inspections.

Subcommittee XVI on Hardware Tests (A. Mendizza, chairman).—The report of this subcommittee is appended hereto under the title "Report of Subcommittee XVI on Field Tests and Inspections of Bare and Metallic Coated Hardware, Structural Shapes, Plates, Bars and Their Products."

TEST SITES

Immediately after the 1951 inspection, the test site at Brunot Island, Pittsburgh was turned back to the Duquesne Light Co. through whose courtesy the site was occupied. All tests at this site were terminated at that time.

The test site at Sandy Hook has been given up because the Army has reactivated the area and has reclaimed a portion of the test site for defense purposes. The reclamation of the site was accomplished without making known to ASTM that it was intended to do this, and in the process many of the galvanized sheets and all individual wire specimens were lost for test purposes.

At the request of the Navy, the test site at Key West was given up and a substitute area was turned over to ASTM. It was decided that the hardware specimens were the only A-5 materials which should be shifted and this was done. The sheets were sent to Middletown, Ohio, for final inspection by Subcommittee XIV.

The American Chain and Cable Co. Inc., has asked for the relinquishment of a portion of the site at Bridgeport, but this will not interfere with the test program as the specimens can be readily consolidated.

This report has been submitted to letter ballot of the committee, which consists of 113 members; 57 members returned their ballots, of whom 51 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee.

T. R. GALLOWAY,
Chairman.

H. F. HORMANN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-5 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Zinc-Coated Steel Overhead Ground Wire Strand (A 363 - 52 T).

Revision and Reversion to Tentative of Standard Specifications for:

Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (A 122 - 41),
and
Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 41).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the new and revised specifications appear in the 1952 Book of ASTM Standards, Part 1.

REPORT OF SUBCOMMITTEE XIV ON INSPECTION OF BLACK AND GALVANIZED SHEETS

The atmospheric tests of corrugated sheets at Annapolis, Md., Altoona, Pa., Brunot Island, Pittsburgh, Pa., Sandy Hook, N. J., and State College, Pa., were inspected in April 1951. It was agreed in 1949 that only Spring inspections would be made.

Brunot Island was abandoned after the 1951 inspection due to the need of the area by the owner.

The specimens at Sandy Hook suffered extensive damage early this year (1952) as a result of Army construction in the immediate vicinity. What light-coated sheets were left were all 100 per cent rust. In addition, the No. 28 gage samples were all perforated.

In January of this year the ASTM Key West test site was relocated due to expansion of Navy facilities. The sheet tests were discontinued at that time and all unperforated specimens were sent to Middletown, Ohio, where a final inspection was made.

As a result of these discontinuations of test sites, the 1952 Spring inspection included only Annapolis, Md., Altoona, Pa., and State College, Pa.

All of the No. 22 gage black sheets have now failed (35.5 yr. exposure) at Annapolis and the complete data are given in Table I.

The data for the final inspections at Brunot Island, Pittsburgh, Pa., Sandy Hook, N. J., and Key West, Fla., are given in Tables III. IV, and VI, respectively.

Tables II and V bring the data given in the 1950 report[1] up to date (26 yr.) for Altoona, Pa. and State College, Pa.

This report has been submitted to letter ballot of Subcommittee XIV and unanimously approved.

Respectfully submitted on behalf of the subcommittee,

E. S. TAYLERSON,
Chairman

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[1] Report of Subcommittee XVI, *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 114 (1950).

TABLE I.—RECORD OF FAILURES AT ANNAPOLIS OF 22 GAGE COPPER-BEARING AND NON-COPPER-BEARING CORRUGATED BLACK SHEETS.

Sheets Exposed October 17, 1916. Inspections Made Semi-Annually From 1917 to 1951.

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test[a]	Life of Each Failed Sheet, yr.																Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr.	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																					
Z......	Open-hearth Steel	B	0.032	0.32	0.063	0.042	.....	0.019	3	13.5	17.0	19.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	16.5	Z
O......	Open-hearth Steel	A	0.121	0.536	0.008	0.030	0.249	0.020	12	7.0	9.0	9.0	9.0	9.0	9.5	10.0	10.0	11.0	11.0	13.0	17.0	...	...	...	...	12	12	10.4	O
B......	Open-hearth Steel	A	0.09	0.38	0.017	0.062	0.036	0.084	3	20.0	20.5	24.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	21.5	B
M......	Open-hearth Steel	B	0.093	0.419	0.013	0.041	0.011	0.185	13	20.0	20.5	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0	...	...	...	13	13	23.4	M
B......	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.187	9	19.5	20.0	21.5	22.0	22.5	23.0	26.0	28.0	28.5	...	...	...	...	...	...	...	9	9	23.4	B
Z......	Open-hearth Steel	B	0.067	0.351	0.045	0.052	0.003	0.187	3	27.0	27.5	28.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	27.5	Z
T......	Open-hearth Steel	B	0.083	0.313	0.009	0.020	0.005	0.227	14	19.5	19.5	19.5	21.5	21.5	21.5	23.0	23.5	23.5	23.5	24.0	24.0	24.0	24.0	...	...	14	14	22.3	T
K......	Open-hearth Steel (Acid)	A	0.107	0.447	0.091	0.046	0.004	0.237	14	24.5	28.0	28.5	28.5	28.5	29.0	29.5	30.0	31.0	31.5	32.0	32.0	32.0	33.5	...	...	14	14	29.9	K
H......	Open-hearth Steel	A	0.069	0.387	0.016	0.027	0.004	0.244	10	19.5	21.0	21.5	23.0	23.5	23.5	23.5	24.0	24.0	25.0	...	...	...	...	...	...	10	10	22.9	H
Z......	Open-hearth Steel	B	0.065	0.35	0.050	0.059	0.003	0.264	2	24.5	28.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	26.3	Z
Z......	Open-hearth Steel	B	0.073	0.42	0.052	0.054	Trace	0.641	3	28.0	29.0	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	30.2	Z
S......	Open-hearth Iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	11.5	12.5	12.5	12.5	12.5	12.5	...	...	14	14	10.6	S
D......	Open-hearth Iron	A	0.02	0.026	0.004	0.022	0.002	0.024	6	16.0	16.0	16.0	19.5	19.5	23.5	...	...	...	...	...	...	...	...	...	...	6	6	18.4	D
X......	Open-hearth Iron	B	0.021	0.055	0.007	0.031	0.004	0.027	14	10.5	13.0	13.5	14.5	14.5	16.0	16.0	16.5	16.5	17.0	17.5	17.5	18.0	19.0	...	...	14	14	15.7	X
C......	Open-hearth Iron	A	0.01	0.028	0.002	0.027	0.002	0.141	3	17.5	20.5	23.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	20.5	C
C......	Open-hearth Iron	A	0.015	0.028	0.006	0.036	0.003	0.194	9	16.5	16.5	18.5	19.0	19.0	20.0	20.5	21.5	21.5	...	...	...	...	...	...	...	9	9	19.2	C
U......	Open-hearth Iron	B	0.017	0.074	0.008	0.037	0.005	0.260	13	15.5	16.5	19.0	19.0	19.0	19.0	19.0	19.5	20.0	20.0	21.0	21.0	22.5	...	...	...	13	13	19.3	U
V......	Open-hearth Iron	B	0.018	0.051	0.007	0.021	0.005	0.304	14	17.0	17.0	17.5	18.5	18.5	19.0	20.0	20.0	20.5	21.0	22.0	22.0	22.5	24.0	...	...	14	14	20.0	V
A......	Bessemer Steel	A	0.038	0.386	0.089	0.040	0.007	0.014	15	15.5	16.5	16.5	17.0	17.0	17.0	18.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	...	15	15	18.2	A
Z......	Bessemer Steel	B	0.063	0.41	0.102	0.044	0.009	0.013	3	11.5	11.5	11.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	11.5	Z
Z......	Bessemer Steel	B	0.077	0.44	0.095	0.036	0.003	0.140	3	27.5	27.5	27.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	27.5	Z
I......	Bessemer Steel	A	0.041	0.365	0.097	0.068	0.008	0.252	15	24.0	26.0	26.5	26.5	26.5	26.5	27.0	28.0	28.0	29.0	29.5	29.5	31.0	31.5	33.5	...	15	15	28.2	I
Z......	Bessemer Steel	B	0.058	0.37	0.093	0.043	0.009	0.269	3	28.0	29.5	31.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	29.5	Z
Z......	Bessemer Steel	B	0.055	0.38	0.110	0.046	.....	0.527	3	32.0	32.5	34.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	33.0	Z
Y......	Wrought Iron	B	0.03	0.055	0.139	0.021	0.218	0.020	3	18.0	19.5	23.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	20.3	Y
E......	Wrought Iron	A	0.033	0.034	0.114	0.021	0.134	0.283	10	19.5	20.5	21.0	21.0	23.0	23.0	23.0	23.0	24.0	25.0	...	...	...	...	...	...	10	10	22.3	E
							Total......		214															Total...		214	214		

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[a] The number of sheets in the test indicated in this table is less than the number shown in earlier reports because certain sheets were discarded due to mechanical damage.

TABLE II.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at Altoona, Pa., on April 22, 1926.

Sheet	No. 16 Gage, 2.5 oz. per sq. ft.[a]		No. 22 Gage, 2.5 oz. per sq. ft.[a]			No. 22 Gage, 2.0 oz. per sq. ft.[a]			No. 22 Gage, 1.5 oz. per sq. ft.[a]			No. 22 Gage, 1.25 oz. per sq. ft.[a]			No. 22 Gage, 0.75 oz. per sq. ft.[a]			No. 28 Gage, 0.75 oz. per sq. ft.[a]			No. 22 Gage, Uncoated
	Years To		Years To			Years To			Years To			Years To			Years To			Years To			
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	Years To Perforation
R (T)	....	....	4.3	12.0	21.0	3.3	9.5	18.5	3.3	5.0	14.5	2.3	4.3	14.5	....	....	....	....	....	....	4.3
(B)			4.5	11.5	21.5	3.3	9.0	16.5	3.3	7.0	17.0	2.3	4.5	16.0							
V (T)	4.3	11.0	4.3	9.0	[b]	3.3	7.0	17.5	2.3	7.0	14.5	2.3	5.2	13.5	1.4	3.3	9.0	....	....	....	4.3(V)
(or U) (B)	4.3	7.0	4.8	9.0	17.5	4.3	6.8	19.0	2.5	7.0	15.0	2.3	4.5	15.0	2.3	3.3	13.0				4.3(U)
N (T)	....	....	4.3	8.5	22.5	3.3	8.5	20.0	3.3	5.5	17.0	2.3	4.5	15.0	1.4	2.8	13.0	2.0	3.3	7.0	7.5
(B)			3.5	12.0	24.0	3.5	8.0	22.0	3.3	5.9	19.0	2.3	4.5	[b]	1.4	3.3	15.0	2.3	3.3	11.0	
T (T)	4.5	10.5	5.5	11.5	22.5	3.5	7.5	20.0	2.3	5.0	18.5	2.3	5.0	15.0	1.4	2.8	13.5	2.0	2.8	9.0	8.5
(B)	4.8	9.0	6.3	11.5	*	3.5	7.0	22.0	2.5	5.2	17.0	2.3	4.3	17.0	2.3	3.0	15.0	2.3	3.3	11.0	
Y (T)	4.3	11.5	3.5	11.5	....	3.3	8.5	....	2.5	5.0	....	2.3	3.3	....	2.3	3.5	....	1.4	3.5	....	....
(B)	4.5	13.7	3.3	9.5	....	4.3	9.0	....	3.3	5.2	....	2.5	4.3	....	2.3	3.3	....	2.3	3.3	....	
S (T)	4.3	12.0	4.3	12.0	22.0	4.3	8.5	20.5	3.0	4.5	19.0	2.3	4.0	17.0	2.0	2.8	13.5	2.0	3.0	7.0	9.0
(B)	4.3	12.5	4.8	14.5	24.0	4.3	8.5	23.0	3.3	6.3	20.5	3.0	4.3	19.0	2.3	2.8	15.0	2.3	3.0	10.5	
C (T)	....	....	4.0	10.5	26.0	3.3	8.5	22.5	2.5	6.5	21.5	2.3	4.5	19.0	1.4	3.5	[b]	....	....	....	
(B)			5.8	13.5	26.0	4.3	10.0	24.0	3.3	6.5	19.0	2.5	4.3	19.5	1.4	3.0	[b]				
K (T)	4.3	12.5	4.3	11.5	25.0	4.3	7.5	24.0	3.3	5.2	21.5	2.5	4.3	[b]	2.3	3.0	[b]	2.3	2.8	10.5	13.0
(B)	4.3	11.5	4.5	11.5	*	4.3	8.5	*	3.3	5.0	25.0	3.3	4.3	21.0	2.3	3.0	21.0	2.3	3.0	10.5	
W (T)	....	....	5.2	10.5	21.5	3.5	6.5	19.0	3.3	5.0	15.0	2.3	4.0	14.5	....	....	....	....	....	....	5.0
(B)			5.2	12.0	23.0	4.3	7.5	19.5	3.3	5.5	17.0	2.3	4.0	15.0							
Average	4.4	11.1	4.6	11.2	....	3.8	8.1	....	3.0	5.7	....	2.4	4.3	....	1.9	3.1	....	2.1	3.1	....	

* Data not yet available.

[a] Coating weight is "oz. per sq. ft." of sheet (both sides).

[b] Blown away or discarded due to mechanical damage.

TABLE III.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at Brunot Island, Pittsburgh, Pa., on April 21, 1926.

Sheet	No. 16 Gage, 2.5 oz. per sq. ft.[a]		No. 22 Gage, 2.5 oz. per sq. ft.[a]			No. 22 Gage, 2.0 oz. per sq. ft.[a]			No. 22 Gage, 1.5 oz. per sq. ft.[a]			No. 22 Gage, 1.25 oz. per sq. ft.[a]			No. 22 Gage, 0.75 oz. per sq. ft.[a]			No. 28 Gage, 0.75 oz. per sq. ft.[a]			No. 22 Gage, Un-coated
	Years To		Years To			Years To			Years To			Years To			Years To			Years To			
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	Years To Perfo-ration
R (T)	5.3	13.5	5.3	13.0	19.5	4.3	14.4	20.0	3.5	8.5	17.5	3.3	6.7	15.5	....	....	....	....	....	....	2.0
(B)	5.5	14.4	5.8	13.5	24.0	4.5	13.0	18.5	3.8	9.5	17.5	3.3	6.7	17.0							
V (T)	5.5	13.5	4.0	12.5	19.5	4.3	9.5	22.0	3.3	11.0	18.5	3.3	7.5	17.5	2.0	4.5	15.5	....	....	....	2.3(V)
(or U) (B)	5.0	12.0(U)	5.5	13.0	23.0	4.8	10.5	20.6	3.3	10.5	18.5	3.3	6.7	18.5	2.3	4.5	13.5				2.5(U)
N (T)	...	....	5.3	12.5	*	4.5	11.5	*	3.3	9.5	19.5	2.5	5.5	19.0	2.0	3.5	16.5	2.3	3.5	10.5	3.0
(B)			5.3	15.5	*	4.8	11.5	*	3.8	8.5	22.5	3.3	6.0	19.5	2.0	3.5	18.0	2.3	4.5	10.5	
T (T)	5.3	12.5	6.3	13.5	*	4.0	11.0	*	3.3	6.7	*	2.5	6.5	23.0	2.3	4.3	19.0	2.0	3.0	10.5	9.0
(B)	5.8	13.5	8.5	15.5	*	4.5	11.0	*	3.3	8.5	22.0	3.3	6.0	24.0	2.3	4.5	19.5	2.3	4.3	12.5	
Y (T)	4.8	14.4	4.5	11.5	....	3.5	11.0	....	3.5	6.7	....	3.3	4.8	....	2.0	4.3	....	2.0	3.8	....	....
(B)	5.5	16.5	5.5	14.0	....	4.5	16.5	....	3.3	8.3	....	3.3	6.0	....	2.3	5.0	....	2.3	4.5	....	
S (T)	4.3	15.5	5.3	15.0	*	4.5	10.5	*	3.5	7.4	19.0	3.3	5.5	21.5	2.3	4.8	14.5	2.3	3.3	4.0	3.3
(B)	5.3	15.5	7.0	18.5	24.0	5.3	12.5	*	3.8	7.4	23.0	3.3	6.0	22.5	2.3	3.5	18.0	2.3	4.0	4.3	
C (T)	...	....	4.3	12.0	*	4.0	11.5	*	3.3	10.5	*	3.3	6.3	*	2.0	4.3	*	....	....	....	12.5
(B)			8.5	18.5	*	4.8	11.0	*	3.3	10.5	*	3.3	6.8	*	2.3	4.5	22.5				
K (T)	4.8	14.0	5.5	15.0	*	4.3	10.5	*	4.0	8.3	*	3.3	5.0	*	2.3	3.5	*	2.3	3.0	14.5	16.5
(B)	5.3	15.5	7.3	16.5	*	5.8	12.5	*	4.3	8.5	*	3.3	6.5	*	2.3	4.0	*	2.3	3.5	14.5	
W (T)	...	....	5.5	12.5	25.0	4.5	9.5	21.5	3.3	7.3	18.0	3.3	5.5	17.5	....	....	....	....	....	....	3.0
(B)			6.3	15.5	*	5.8	12.5	22.0	3.3	7.3	13.0	3.3	6.0	19.5							
Average	5.2	14.3	5.9	14.4	....	4.6	11.7	....	3.5	8.6	....	3.2	6.1	....	2.2	4.2	....	2.2	3.7	....	....

* Not perforated at end of test (25 years).

[a] Coating weight is "oz. per sq. ft." of sheet (both sides).

TABLE IV.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at Sandy Hook, N. J., on May 20, 1926.

Sheet	No. 16 Gage, 2.5 oz. per sq. ft.[a]		No. 22 Gage, 2.5 oz. per sq. ft.[a]		No. 22 Gage, 2.0 oz. per sq. ft.[a]		No. 22 Gage, 1.5 oz. per sq. ft.[a]		No. 22 Gage, 1.25 oz. per sq. ft.[a]		No. 22 Gage, 0.75 oz. per sq. ft.[a]		No. 28 Gage, 0.75 oz. per sq. ft.[a]			No 22 Gage, Un-coated
	Years To		Years To		Years To		Years To		Years To		Years To		Years To			Years To Perfo-ration
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	
R (T)	13.4	25.0	12.4	*	8.4	*	6.4	17.9	7.4	14.4	....	....	....	....	....	5.9
(B)	13.4	*	12.9	*	9.4	21.9	7.4	19.4	6.9	15.9						
V (T)	12.4	24.0	10.9	24.0	9.9	19.4	7.4	19.9	6.4	19.4	5.4	13.4	....	....	....	4.9(V)
(or U) (B)	10.9	25.0 (U)	12.4	23.0	10.4	19.4	6.9	20.4	7.4	15.4	4.5	11.0				5.4(U)
N (T)	....	....	11.4	*	9.4	*	7.4	18.4	6.9	15.4	4.5	11.4	4.5	11.4	24.0	5.9
(B)			10.4	*	9.9	20.9	7.4	17.4	5.9	15.4	4.5	11.0	6.4	12.0	25.0	
T (T)	12.4	25.0	15.9	*	9.9	23.0	6.9	17.9	5.9	15.9	4.5	13.4	4.5	13.4	20.9	6.4
(B)	12.4	24.0	16.4	*	9.9	19.4	6.9	14.4	5.4	15.4	4.5	11.0	5.4	12.0	25.5	
Y (T)	10.9	*	11.4	23.0	8.4	*	7.4	17.4	6.4	16.4	4.5	11.0	4.5	12.0	....	....
(B)	12.4	*	13.4	*	8.4	24.0	8.4	17.9	6.9	13.4	5.4	13.4	4.5	11.4	....	
S (T)	10.4	*	11.9	*	9.9	21.4	7.4	15.9	5.9	12.9	4.5	9.9	4.5	9.4	20.9	9.9
(B)	11.4	*	13.4	*	12.4	23.0	9.4	16.9	7.4	15.4	4.9	9.4	5.4	9.4	25.5	
C (T)	....	....	11.4	*	8.4	25.0	7.4	19.4	6.9	15.4	4.5	12.4	....	....	....	10.4
(B)			18.4	*	9.4	24.0	7.4	19.4	7.4	14.4	4.5	11.4				
K (T)	10.9	*	11.4	*	10.4	20.9	8.4	15.9	7.4	13.9	4.5	9.4	4.5	10.0	24.0	12.4
(B)	10.4	*	12.9	*	11.4	23.0	8.4	17.4	7.4	13.9	6.4	10.4	4.9	10.0	25.0	
W (T)	....	....	13.4	*	11.4	23.0	8.4	17.4	7.4	14.4	....	....	....	....	....	4.9
(B)			14.4	*	11.4	21.9	7.4	19.4	6.4	16.4						
Average	11.8	....	13.1	....	9.9	....	7.6	17.9	6.8	15.2	4.8	11.3	4.9	11.1	....	....

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* Not perforated at end of test (25 years).

[a] Coating weight is "oz. per sq. ft." of sheet (both sides).

TABLE V.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.

Exposed at State College, Pa., on April 23, 1926.

Sheet	No. 16 Gage, 2.5 oz. per sq. ft.[a] Years To		No. 22 Gage, 2.5 oz. per sq. ft.[a] Years To			No. 22 Gage, 2.0 oz. per sq. ft. Years To			No. 22 Gage, 1.5 oz. per sq. ft.[a] Years To			No. 22 Gage, 1.25 oz. per sq. ft.[a] Years To			No. 22 Gage, 0.75 oz. per sq. ft.[a] Years To			No. 28 Gage, 0.75 oz. per sq. ft.[a] Years To			No. 22 Gage, Un-coated
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 Per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	Years To Perforation
R (T)	24.0	*	26.0	*	*	19.0	*	*	17.5	*	*	14.5	*	*	....	....	....	....	....	....	*
(B)	*	*	*	*	*	20.0	*	*	16.5	*	*	15.0	*	*							
V (T)	*	*	21.5	*	*	18.5	*	*	16.0	*	*	15.0	*	*	9.5	23.0	*				24.0(V)
(or U) (B)	24.0	*	*	*	*	25.0	*	*	15.5	*	*	16.5	*	*	10.5	24.0	*	....	....	....	* (U)
N (T)	....	....	20.5	*	*	22.5	*	*	17.5	*	*	12.0	*	*	6.5	20.5	*	11.0	23.0	*	*
(B)			*	*	*	22.5	*	*	15.5	*	*	13.5	*	*	9.0	23.0	*	11.5	*	*	
T (T)	*	*	*	*	*	21.0	*	*	16.0	*	*	15.0	*	*	9.0	26.0	*	9.0	24.0	*	*
(B)	*	*	*	*	*	23.0	*	*	14.5	*	*	13.5	*	*	10.5	22.5	*	12.0	25.0	*	
Y (T)	21.5	*	22.5	*	....	19.5	*	....	17.5	*	....	14.5	*	....	10.0	22.5	....	9.5	24.0	....	....
(B)	22.5	*	*	*	....	19.0	*	....	18.5	*	....	14.5	*	....	10.5	*	....	13.0	26.0	....	
S (T)	22.0	*	*	*	*	25.0	*	*	19.0	*	*	14.5	*	*	10.5	21.5	*	11.5	22.0	*	*
(B)	22.5	*	*	*	*	*	*	*	19.5	*	*	15.5	*	*	11.0	21.5	*	11.5	21.5	*	
C (T)	....	....	22.5	*	*	17.5	*	*	16.0	*	*	14.5	*	*	9.5	24.0	*	....	....	....	*
(B)			*	*	*	21.5	*	*	18.5	*	*	14.5	*	*	10.0	24.0	*				
K (T)	23.0	*	25.0	*	*	22.5	*	*	17.5	*	*	14.5	*	*	11.5	24.0	*	10.5	23.0	*	*
(B)	24.0	*	*	*	*	*	*	*	21.0	*	*	16.5	*	*	11.5	22.5	*	11.5	21.0	*	
W (T)	....	....	*	*	*	25.0	*	*	16.5	*	*	13.5	*	*	....	....	....	....	....	....	*
(B)			*	*	*	*	*	*	15.0	*	*	14.5	*	*							
Average	....	....		....	....	....	....	....	17.0	....	....	14.6			10.0			11.1			

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* Data not yet available.

[a] Coating weight is "oz. per sq. ft." of sheet (both sides).

TABLE VI.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS 26 BY 30 IN.
Exposed at Key West, Fla. on June 9, 1926.

Sheet	No. 16 Gage, 2.5 oz per sq ft.[a]		No. 22 Gage, 2.5 oz per sq ft.[a]		No. 22 Gage, 2.0 oz per sq ft.[a]		No. 22 Gage, 1.5 oz per sq ft.[a]		No. 22 Gage, 1.25 oz per sq ft.[a]			No. 22 Gage, 0.75 oz per sq ft.[a]			No. 28 Gage, 0.75 oz per sq ft.[a]			No. 22 Gage, Un-coated
	Years to		Years to		Years to		Years to		Years to			Years to			Years to			
	Spots	Perforation	Spots	Perforation	Spots	Perforation	Spots	Perforation	1st Rust	Spots	Perforation	1st Rust	Spots	Perforation	1st Rust	Spots	Perforation	Years to Perforation
R (T)	24.8	*	*	*	19.8	21.5	20.8	21.5	*	14.8	17.8	....	....	....	....	....	....	
(B)	19.8	20.8	22.8	25.5	17.8	19.8	11.8	17.8	*	11.8	14.8	....	....	....	....	....	....	3.6
V (T)	19.8	21.5 (U)	19.8	21.5	17.8	20.8	19.8	21.5	*	11.8	17.8	13.8	14.8	17.8	....	....	....	3.6(U)
or U) (B)	24.8	25.5 (U)	19.8	21.5	17.8	19.8	12.8	17.8	*	12.8	17.8	19.8	11.8	14.8	....	....	....	3.6(V)
N (T)	....	....	25.5	*	21.5	24.8	12.8	22.8	21.5	13.8	14.8	17.8	10.6	11.8	19.8	12.8	21.5	
(B)	....	....	20.8	25.5	19.8	21.5	13.8	17.8	21.5	11.8	17.8	17.8	11.8	17.8	20.8	19.8	20.8	3.6
T (T)	19.8	21.5	*	*	22.8	25.5	12.8	17.8	*	17.8	21.5	17.8	12.8	20.8	17.8	10.6	21.5	
(B)	24.8	*	*	*	17.8	17.8	13.8	17.8	*	11.8	17.8	17.8	10.6	14.8	17.8	12.8	17.8	3.6
Y (T)	25.5	....	20.8	....	....	....	19.8	....	*	10.6	....	21.5	11.8	....	19.8	11.8	....	
(B)	17.8	....	24.8	....	11.8	....	11.8	....	*	10.6	....	21.5	10.6	....	19.8	13.8	....	....
S (T)	*	*	24.8	*	24.8	25.5	11.8	21.5	*	12.8	17.8	19.8	11.8	14.8	17.8	11.8	14.8	
(B)	17.8	19.8	22.8	25.5	17.8	21.5	13.8	17.8	*	13.8	17.8	19.8	10.6	14.8	17.8	10.6	11.8	3.6
C (T)	....	....	*	*	*	*	17.8	17.8	*	12.8	14.8	19.8	12.8	25.5	....	....	....	5.7
(B)	....	....	22.8	25.5	20.8	21.5	12.8	17.8	*	13.8	17.8	13.8	11.8	14.8	....	....	....	
K (T)	*	*	*	*	20.8	*	12.8	19.8	*	17.8	20.8	17.8	22.8	22.8	17.8	14.8	21.5	
(B)	*	*	20.8	25.5	19.8	24.8	17.8	21.5	*	14.8	17.8	17.8	10.6	19.8	17.8	11.8	21.5	4.6
W (T)	....	....	*	*	22.8	*	13.8	24.8	*	*	25.5	....	....	....	....	....	....	
(B)	....	....	25.5	*	22.8	25.5	19.8	21.5	*	19.8	22.8	....	....	....	....	....	....	3.6

[a] Coating weight is "oz. per sq. ft." of sheet (both sides).

* Had not failed at end of test January, 1952 (25.5 yr.)

1st Rust is based on same standards as at other test locations and ignores spots originating from below.

Spots—First sign on top surface of corrosion originating from underside of sheet. These yellow spots blister and crack and finally become "perforations."

REPORT OF SUBCOMMITTEE XVI ON FIELD TESTS AND INSPECTIONS OF BARE AND METALLIC COATED HARDWARE STRUCTURAL SHAPES, PLATES, BARS, AND THEIR PRODUCTS

The data obtained in the routine annual inspections of the three remaining test locations have been assembled in Table I. These inspections were made in the spring of 1951 and 1952. The last tabulated report for the Key West location prior to the present one appears in the 1948 report[1] for the inspection made in April, 1947.

State College, Pa.:

No significant changes have occurred at this location.

Key West, Fla.:

A considerable number of samples have been removed from test since the 1947 inspection and do not appear in the present report. The remaining samples consist chiefly of hot-dip galvanized, hot-dip aluminum, and lead-coated specimens. There are also a few sherardized and some electroplated zinc samples remaining on test. The No. 161 window frame sections had not been reported in the 1948 report. The variously sherardized and calorized 1-in. tubular goods samples are mixed up to the extent that an intelligent rating is not possible. As compared with the previously reported inspection data,[1] hot-dip galvanized and the lead-coated samples have not changed appreciably. Significant changes have been observed on most of the hot-dip aluminum samples. The test site at Key West has been relocated. This new location is thought to be similar to the old site from the standpoint of environmental atmospheric conditions.

Sandy Hook, N. J.:

The progress of corrosion at this site is relatively slow and no appreciable over-all changes have been observed. A considerable number of specimens have been lost as a result of vandalism. In view of the possibility of further damage to the test plot it has been decided to abandon it. An attempt will be made to salvage the remaining samples for possible laboratory studies.

Altoona and Brunot Island, Pa.:

All tests at these locations have been discontinued. The last report appears in the 1944 report.[2]

Respectfully submitted on behalf of the subcommittee,

A. MENDIZZA,
Chairman.

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[1] Report of Subcommittee XVI on Field Tests and Inspections of Bare and Metallic Coated Hardware, Structural Shapes, Plates, Bars, and Their Products, *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 119 (1948).

[2] Report of Subcommittee VIII on Field Tests of Metallic Coatings, *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 92 (1944).

TABLE I.—REPORT OF INSPECTIONS ON HARDWARE, STRUCTURAL SHAPES, TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT THREE LOCATIONS.

Abbreviations and symbols used: 0, no rust; 5, 10, 25, 100, approximate percentages; R, rusting of base metal; R*, rust spots widely distributed; Y, yellow or orange rust; D, black or dark surface films (soot or dirt); Tr, trace; X, 100 per cent rust listed in previous reports; TH, threads; a, samples mixed; b, average of nipple and ell; c, only one specimen remaining; and d, all samples lost since last inspection. Blank spaces indicate samples removed in 1942.

Coating	Weight, oz per sq ft of surface	Exposure at State College, Pa.		Exposure at Sandy Hook, N. J.		Exposure at Key West, Fla.	
		4-25-51 1146 Weeks	4-30-52 1198 Weeks	4-24-51 1156 Weeks	4-29-52 1208 Weeks	3-8-51 1082 Weeks	5-6-52 1142 Weeks
3 BY 3 BY 5/16-IN. PLAIN STEEL ANGLES							
Hot-dip galvanized	2.52	0	0	10Y	TrR-20Y (c)	0	TrY
Hot-dip aluminium	0.89	0	0D	0	0	10Y	TrR
Electric Sherardized	1.38	TrR-100Y	TrR-100Y	...	...	100Y	5R-100Y
Lead-coated	...	TrR-85R*	TrR-85R*	...	...	70R*	TrR-90R*
3 BY 3 BY 5/16-IN. COPPER-BEARING STEEL ANGLES							
Hot-dip galvanized	2.88	TrY	TrY	TrY	(d)	0	TrY
Hot-dip aluminum	0.82	0D	0D	0	0	10Y	TrR
Electric Sherardized	1.44	5R-95Y	5R-100Y	...	...	100Y	TrR-100Y
Lead-coated	...	TrR-90R*	TrR-90R*	...	...	70R*	TrR-95R*
2 BY 1½ BY 5/16-IN. PLAIN STEEL ANGLES							
Hot-dip galvanized	3.24	TrY	TrY	TrR-TrY	TrR-TrY	0	0
Hot-dip aluminum	0.75	0	0	0	TrY	20R	60R
Lead-coated	...	80R*	80R*	5R-80R*	(d)	95R*	TrR-95R*
2 BY 1½ BY 5/16-IN. COPPER-BEARING STEEL ANGLES							
Hot-dip galvanized	2.75	0	0	TrY	TrR-TrY	0	0
Hot-dip aluminum	0.50	0	0	0	0 (c)	5R	25R
Lead-coated	...	TrR-90R*	TrR-80R*	...	...	95R*	TrR-95R*
2-IN. DIAMETER TUBULAR GOODS							
Electrogalvanized	1.58	0	0	...	...	0	0
Hot-dip galvanized	2.51	TrY	TrY	TrR-20Y	20Y	0	0
Hot-dip aluminum	4.73	0	0	10Y	5Y	30Y	15R
Gas Sherardized	0.66	30R-70Y	30R-70Y	...	...	10Y-80R*	100Y-40R*
Lead-coated	...	5R-100R*	5R-100R*	10R-95R*	20R-100R* (c)	...	...

[Continued on pages 120 to 122.]

TABLE I.—(*Continued*)

Coating	Weight, oz per sq ft of surface	Exposure at State College, Pa.		Exposure at Sandy Hook, N. J.		Exposure at Key West, Fla.	
		4-25-51 1146 Weeks	4-30-52 1198 Weeks	4-24-51 1156 Weeks	4-29-52 1208 Weeks	3-8-51 1082 Weeks	5-6-52 1142 Weeks
1-IN. DIAMETER TUBULAR GOODS							
Electrogalvanized	1.62	0	0	...	...	0	0
Hot-dip galvanized	1.83	TrR-90Y	TrR-80Y	...	...	0	TrR-5R*
Hot-dip aluminum	1.83	0	0	...	...	30R	30R
Electric Sherardized	0.92	50R-50Y	30R-70Y	...	...	(a)	(a)
Gas Sherardized	0.72	60R-40Y	70R-30Y	...	...		
Calorized	...	100Y	100Y	...	...		
Lead-coated	...	TrR-70R*	TrR-70R*	...	...	100R*	TrR-100R*
Amaloy	...	TrR-90R*	TrR-95R*	...	...		
FORGED STEEL TOWER FITTINGS							
Hot-dip galvanized	2.67	TrR-60Y	60Y	...	...	10Y	TrR*
Hot-dip galvanized	1.53		TrR-80Y	...	...		
Hot-dip Aluminum	...	0	0	...	...	10Y-75R	80R
Electric Sherardized	0.50	45R-70Y	25R-70Y	...	...	...	...
¾-IN. NIPPLES AND ELLS							
Electrogalvanized M1	1.60	TrY-TrR	5R		(a)	(a)	(a)
Electrogalvanized C1	2.19	20R-10Y	25R-10Y				
Electrogalvanized M1	2.65	R in TH-50R-20Y	50R-20Y				
Electrogalvanized C1	1.25	50R-30Y	50R-20Y				
Hot-dip galvanized M1	1.82	90Y	80Y	20R-95Y			
Hot-dip galvanized C1	1.44	90Y	80Y				
Hot-dip aluminum M1	3.20	R in TH-TrY	TrR in TH	100R in TH			
Hot-dip aluminum C1	2.80	R in TH	R in TH				
Electric Sherardized M1	0.75	10R-90Y	15R-90Y				
Amaloy M1 and C1	...	20R-90R*	20R-80R*	10R-80R*			
TOWER CLAMPS							
Hot-dip galvanized M1	2.00	5Y	5Y	10R-85Y	15R-75Y	TrR	TrR*
Hot-dip galvanized C1	2.38						
Hot-dip aluminum M1	3.16	0	0	0	TrY	80R	75R
Hot-dip aluminum C1	2.51						
1½ BY 1½ BY ⅛-IN. PLAIN STEEL ANGLES							
Hot-dip galvanized	3.16	0	TrY	5R-15Y	5R-10Y	0	0
Hot-dip aluminum	0.89	0	0	0	0	10Y	5R
Lead-coated	...	TrR-80R*	80R*	10R-80R*	10R-60R*	80R*	100R*

1½ BY 1½ BY ⅛-IN. COPPER-BEARING STEEL ANGLES						
Hot-dip galvanized	3.20	TrY	TrY	TrR-10Y	10Y	0	TrY
Hot-dip aluminum	1.11	0	0	0	0	10Y	5R
Lead-coated	...	TrR-90R*	TrR-90R*	TrY-70R*	TrR-50R*	70R*	TrY-90R*
NO. 14 GAGE BY 2½-IN. PLAIN STEEL FLATS							
Hot-dip galvanized	3.16	...	...	10R-20Y	(d)	0	TrR
Hot-dip aluminum	0.89	...	...	0	(d)	25R	20R
Lead-coated	...	...	...	TrR-80R*	(d)	80R*	TrR-100R*
NO. 14 GAGE BY 2½-IN. COPPER-BEARING STEEL FLATS							
Hot-dip galvanized	3.20	TrY	TrY	...	...	0	
Hot-dip aluminum	0.47	0	0	...	...	5R	TrR
Lead-coated	...	70R*	60R*	...	...	80R*	TrR-100R*
KNOCKOUT BOXES							
Hot-dip galvanized	1.50	25Y	20Y	20R-80Y	30R-65Y	TrR	TrR
Electric Sherardized	0.28	TrR-100Y	TrR-100Y	...	...	100Y	40R-60Y
Amaloy	...	TrR-95R*	TrR-100R*	15R-80R*	30R-70R*	...	...
Hot-dip aluminum	1.84	0	0	TrY	TrY	20R*	30R*
BULLDOG CLAMPS							
Hot-dip galvanized	1.88	...	...	80R-20Y	(d)	TrR	TrR
Hot-dip aluminum	1.35	0	0	TrY	(d)	25R	30R
¼ BY 3-IN. PLAIN STEEL FLATS							
Hot-dip galvanized	2.49	TrY	TrY	5R-20Y	TrR-5Y (c)	0	0
Hot-dip aluminum	0.90	0	0	TrY	(d)	10Y	TrR
Lead-coated	...	5R-90R*	5R-90R*	10R-70R*	5R-60R* (c)	...	...
¼ BY 3-IN. COPPER-BEARING STEEL FLATS							
Electrogalvanized	0.66	30R-70Y	30R-70Y	...	...	TrR	TrR
Hot-dip galvanized	2.67	TrY	TrY	5R-10Y	5R-TrY	0	0
Hot-dip aluminum	0.66	0	0	TrY	TrY	TrR	TrR
Lead-coated	...	TrR-90R*	TrR-90R*	10R-75R*	5R-60R* (c)	...	...
NO. 209 WINDOW FRAME SECTION							
Hot-dip galvanized	3.10	...	...	...	...	0	TrY
Hot-dip aluminum	0.61	...	...	...	...	20Y	10R
Amaloy	...	...	...	...	...	95R*	100R*

[Continued on page 122.]

TABLE 1.—(*Continued*)

Coating	Weight, oz per sq ft of surface	Exposure at State College, Pa.		Exposed at Sandy Hook, N. J.		Exposed at Key West, Fla.	
		4-25-51 1146 Weeks	4-30-52 1198 Weeks	4-24-51 1156 Weeks	4-29-52 1208 Weeks	3-8-51 1082 Weeks	5-6-52 1142 Weeks
No. 792 WINDOW FRAME SECTION							
Electrogalvanized	0.54	...	...	...	...	10R	10R
Electrogalvanized	0.35	...	...	...	...		
Hot-dip galvanized	2.60	TrY	TrY	5R-20Y	10R-20Y	TrY	TrR
Hot-dip aluminum	1.39	0	0	0	0	5R	TrR
Electric Sherardized	0.57	...	...	...	...	10R-100Y	80R*-100Y
No. 161 WINDOW FRAME SECTION							
Hot-dip galvanized	...	...	...	...	...	0	TrY
Hot-dip aluminum	...	...	...	...	...	25R	15R
Sherardized	...	...	...	...	...	100Y	50R*-100Y

REPORT OF COMMITTEE A-6

ON

MAGNETIC PROPERTIES*

Since the last report, presented in June 1949, which included an extensive revision and regrouping of the Standard Methods of Testing Magnetic Materials (A 34 - 48), Committee A-6 has held four well-attended meetings.

The present officers have been reelected for the ensuing term of two years. There have been some changes in the membership which include the transfer of P. E. Cavanagh and Theodore Zuschlag to Committee E-7 on Non-Destructive Testing, the resignation of the Navy Bureau of Aeronautics (represented by E. J. Greene) and the appointment of D. S. Muzzey to replace E. A. Gaugler as the representative of the Navy Bureau of Ordnance.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1949 Annual Meeting, Committee A-6 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revision of Standard Methods of:

Testing Magnetic Materials (A 34 - 49),
Test for Permeability of Feebly Magnetic Materials (A 342 - 49), and
Test for Electrical and Mechanical Properties of Magnetic Materials (A 344 - 49).

These recommendations were accepted by the Standards Committee on January 19, 1951, and the tentative revisions appear in the 1950 Supplement to Book of ASTM Standards, Part 1.

TENTATIVE REVISIONS CONTINUED

In order to permit further study, the committee recommends the retention of the following tentative revisions for another year:

Standard Methods of:

Testing Magnetic Materials (A 34 - 49),[1] and
Test for Permeability of Feebly Magnetic Materials (A 342 - 49).[1]

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the Tentative Revision of Standard Methods of Tests for Electrical and Mechanical Properties of Magnetic Materials (A 344 - 49) with the addition as Section 17 (*d*) of Section 12 (*d*) of the present Standard Methods A 344 - 49[2] and accordingly asks the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society for adoption as standard.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 1.

[2] 1949 Book of ASTM Standards, Part 1.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 20 members; 20 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

R. L. SANFORD,
Chairman.

R. C. Taylor,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-6 presented to the Society through the Administrative Committee on Standards a tentative revision of Standard Methods of Test for Alternating Current Core Loss and Permeability of Magnetic Materials (A 343 – 49). This recommendation was accepted by the Standards Committee on September 5, 1952, and the tentative revision appears in the 1952 Book of ASTM Standards, Part 1.

REPORT OF COMMITTEE A-7

ON

MALLEABLE IRON CASTINGS*

Committee A-7 on Malleable Iron Castings held two meetings during the year; the first at Atlantic City, New Jersey, on June 20, 1951, and the second in Cleveland, Ohio, on March 3, 1952.

During the year one new member was added to the committee and there was one removal. At the present time the committee consists of 55 members: 27 are classified as producers, 15 as consumers and 13 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. A. Kennedy.
Vice-Chairman, W. F. Collins.
Secretary, J. H. Lansing.

The two members-at-large elected to the Advisory Committee were V. A. Crosby, Climax Molybdenum Co. and F. G. Steinebach, *Foundry Magazine*.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee A-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine and Other Heavy Duty Service (A 338–51 T).

Withdrawal of Tentative Specifications for:

Malleable Iron Flanges, Pipe Fittings, and Valve Parts (A 277–44 T).

These recommendations were accepted by the Standards Committee on September 12, 1951, and the new tentative specifications appear in the 1951 Supplement to Book of ASTM Standards, Part 1.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision in the Standard Specifications for Malleable Iron Castings (A 47−48)[1] and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

Section 7(*a*).—Revise to read as follows:

> 7. (*a*) If specified by the purchaser, or if their inclusion is standard practice, as in the case of some railroad castings, test lugs shall be cast on all castings of sufficient size to permit their incorporation. They shall be of a size proportional to the thickness of the casting. On castings which are 24 in. or over in length, a test lug shall be cast near each end. The test lugs shall be attached to the castings at such locations that they will not interfere with the assembling of the castings, and may be broken off by the inspector.

The recommendation appearing in this report has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 1.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing, (C. T. Eakin, chairman) has initiated some work bearing on impact properties at normal and sub-normal temperatures and the problem of arriving at suitable test methods as applied to malleable iron and its related metals.

Subcommittee III on Air Furnace, Electric, and Multiplex Malleable Iron (J. H. Lansing, chairman) has recommended to Committee A-7 that the Standard Specifications for Malleable Iron Castings (A 47 – 48),[1] be modified so that greater freedom will be allowed in the provision relative to the requirement for test coupons that are to be cast integral with production castings, a suggestion that is referred to earlier in this report.

This report has been submitted to letter ballot of the committee, which consists of 54 voting members; 40 members returned their ballots, of whom 40 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. A. KENNEDY,
Chairman.

J. H. LANSING,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-9 ON FERRO-ALLOYS*

Committeee A-9 on Ferro-Alloys held its last meeting in Atlantic City, N. J., June 28, 1950. The next meeting of the committee will be held in New York City at the Annual Meeting on June 24, 1952. A meeting of the Joint Coordinating Committee of A-1, A-9, A-10, B-2 and B-4 was held on November 15, 1951, in Philadelphia, Pa., to consider a proposed change in the title and scope of Committee A-9. The committee recommendations were submitted to letter ballot of the committee, which resulted in five negative votes and enough debate to warrant that this matter be placed on the agenda of a full committee meeting to be held in June. The proposed change in scope was considered at a meeting held on June 24 at the 1952 Annual Meeting. A slight modification in the wording of the scope was voted at the meeting, which the committee hopes will be satisfactory to the Board and to other committees which might be involved.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. C. Bowden.
Vice-Chairman, E. A. Lucas.
Secretary, G. F. Comstock.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Molybdenum Salts and Compounds (A 146 – 50 T),[1]
Ferroboron (A 323 – 50 T),[1] and
Ferrotitanium (A 324 – 50 T).[1]

The recommendations appearing in this report have been approved by letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee, which consists of 28 members; 28 members returned their ballots, of whom 20 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. C. BOWDEN, JR.,
Chairman.

G. F. COMSTOCK,
Secretary.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 1.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL AND RELATED ALLOYS*

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held meetings at Atlantic City, N. J., on June 21, 1951, during the Annual Meeting of the Society, and on March 5, 1952, at Cleveland, Ohio.

The present committee consists of 93 members, of whom 41 are classified as producers, 37 as consumers, and 15 as general interest members.

Committee A-10 expresses its regret at the demise of J. K. Findley, former chairman of Subcommittee VIII, and H. A. Grove, former chairman of Subcommittee IX.

L. L. Wyman and M. A. Cordovi have been designated to represent Committee A-10 on a Committee B-2, Subcommittee VII Task Group working on specifications for Hastelloy C.

The election of officers for the ensuing terms of two years resulted in the selection of the following:

Chairman, Jerome Strauss.
Vice-Chairman, L. L. Wyman.
Secretary, M. A. Cordovi.

REVISED SCOPE

Subsequent to the 1951 Annual Meeting, Committee A-10 voted unanimously to request to have its scope revised as follows:

"In general, Committee A-10 has jurisdiction over the classification, specification requirements, methods of test, questions of utility and related subjects pertaining to those iron-base and other chromium-bearing alloys termed "stainless," "rustless," or "heat resistant," whose primary characteristic is resistance to corrosive attack, elevated temperatures, or both."

The above recommendation was presented to the Society through the Coordinating Committee of Committees A-1, A-9, A-10, B-2, and B-4, and was approved by the Board of Directors on May 6, 1952. The Board of Directors has authorized the committee to engage in the formulation of specifications and other activities pertaining to the so-called "jet" or "super" alloys.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, the Emergency Alternate Provisions submitted by Committee A-10 and shown in Table I, were accepted by the Administrative Committee on Standards on the date indicated.

These emergency provisions have been published in the ASTM BULLETIN and have also been issued in the form of pink stickers for attachment to the standards to which they apply.

On October 29, 1951, the Administrative Committee on Standards accepted the following recommendations which Committee A-10 submitted jointly with Committee A-1 on Steel and which appear in the 1951 Supplement to Book of ASTM Standards, Part 1:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Revision of Tentative Specifications for:

Seamless and Welded Austenitic Steel Pipe (A 312 – 51 T).

Tentative Revision of Standard Specifications for:

Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 47).

TABLE I.

Designation	Emergency Alternate Provisions In	Date Issued
	Standard Specifications for:	
EA - A 167	Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 44)	Aug. 21, 1951
EA - A 240	Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (A 240 – 49)	Aug. 21, 1951
*EA - A 268	Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 47)	July 10, 1951
*EA - A 269	Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 47)	July 10, 1951 and Oct. 18, 1951
*EA - A 270	Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 – 50)	July 10, 1951
*EA - A 271	Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 47)	July 10, 1951 and Oct. 18, 1951
	Tentative Specifications for:	
EA - A 276	Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 – 49 T)	Aug. 21, 1951
EA - A 296	Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 296 – 49 T)	Aug. 21, 1951
EA - A 312	Seamless and Welded Austenitic Stainless Steel Pipe (A 312 – 51 T)	July 10, 1951 and Oct. 18, 1951
EA - A 314	Corrosion-Resisting Steel Billets and Bars for Reforging (A 314 – 47 T)	Aug. 21, 1951

* Jointly with Committee A-1.

WITHDRAWAL OF RECOMMENDATION

The recommendation for a proposed tentative specification for Iron-Chromium and Iron-Chromium-Nickel Alloy Tubular Centrifugal Castings for General Applications, as preprinted in the report, was withdrawn by the committee.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Committee A-10 joins with Committee A-1 in recommending for immediate adoption revision of the following standards and accordingly asked for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (**A 269 – 47**):

Section 14 (*b*).—Change to read as follows: (*b*) All tubes to be pickled free from scale.

Standard Specifications for Seamless Austenitic Chromium Nickel Steel Still Tubes for Refinery Services (**A 271 – 47**):

Section 16 (*b*).—Change to read as follows: (*b*) All tubes to be pickled free from scale.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

PENDING REVISION

The committee is considering submitting to the Society the following revisions of Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels.

Section 2(d).—Change present Section 2(*d*) to 2(*c*) and add new Section 2(*d*) as follows:

(*d*) When a large number of specimens are to be tested it is permissible to use a multi-sample testing apparatus especially designed for this purpose and capable of accommodating 40 specimens at one time.[2] The essential parts of this equipment are a steam-jacketed silicon iron kettle with an integrally cast cup in the bottom and fitted with a reflux condenser fabricated of stainless steel.[2] Purified condensed acid drips from the reflux condenser into the cup and overflows from it into the main body of acid kept at a lower level in the kettle proper. With redistilled acid flowing through the cup at a rate of about four cup volumes per hour the concentration of corrosion products in the acid in the cup will always be less than that encountered with the conventional testing apparatus. Because of this lesser accumulation of corrosion products in the acid in contact with the test pieces, their rates of corrosion in the multi-sample apparatus are consistently lower than observed with single specimens in the conventional apparatus.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[2] For details, see W. B. DeLong, "Testing Multiple Specimens of Stainless Steel in a Modified Boiling Nitric Acid Test Apparatus," Symposium on Evaluation Tests for Stainless Steels, Am. Soc. Testing Mats., p. 211 (1950). (Issued as *STP No. 93.*)

Section 5(c).—Change last sentence to read as follows:

After each test period, the specimens should be rinsed with water and treated by scrubbing with rubber or a nylon brush under running water to remove any adherent corrosion products, after which they should be dried and weighed (Section 2(*e*)). Drying may be facilitated if desired by dipping the specimens in acetone after they are scrubbed.

Section 6(b).—Add note as follows:

NOTE.—A specimen which exhibits high corrosion rates in the boiling nitric acid solution may not be attacked intergranularly. Accordingly, in order to establish whether or not intergranular attack has occurred in specimens exhibiting high corrosion rates, a metallographic examination of the corroded specimens is suggested. This examination is not a mandatory requirement of the test.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee IV on Methods of Corrosion (F. L. LaQue, chairman) expects to get the atmospheric corrosion test program under way shortly. New working sub groups have been appointed to tend to the several details of executing the program. By letter ballot it was decided to include in the program the 18 per cent chromium-4 per cent nickel-4 per cent manganese steel that had been dropped previously. The principal present effort is an exploration of the immediate availability of the large amount of specimen material that will be required from the several producers. Further action will be dependent on the results of this effort.

A sub-group under the chairmanship of E. G. Holmberg has continued efforts to prepare a recommended practice for "Cleaning of Stainless Steel Surfaces," particularly in connection with fabricated equipment. A series of drafts have been circulated for suggestions for revision and the results have been discussed at meetings of the sub-group. Considerable progress has been made and it is hoped that it will be possible to present a final draft for formal action at the June, 1952 meeting leading to its adoption by the Society as a new tentative recommended practice.

A special sub-group has been organized under the chairmanship of C. P. Larrabee to institute some special tests in the Pittsburgh area to compare directly the performance of 17 per cent chromium and 18 per cent chromium-8 per cent nickel steels under conditions that will simulate the exposure of these steels on certain buildings in which they have been used extensively in the city of Pittsburgh.

Subcommittee V on Mechanical Testing (R. H. Heyer, chairman).—A Task Group on Flat Rolled Products has been engaged in conducting a program of tension testing to determine the effect of speed of testing on the tensile properties of Type 301 steel; also to study methods of determining yield strength as applied to the austenitic grades. Progress reports from the two cooperating laboratories were presented at the June 18, 1951, meeting in Atlantic City and the March 5, 1952, meeting in Cleveland. Approximately one half of the testing has been completed. Improvements in testing equipment and techniques have resulted from this program. H. T. Oatman has replaced R. A. Lincoln as chairman of the Task Group.

A task group representing Subcommittees V and IX has recommended changes in methods of testing plates in Specifications A 167, A 176, and A 240.

Subcommittee VI on Metallography (Russell Franks, chairman) has been engaged in determining whether the sigma phase can be identified by use of an etching reagent in the austenitic chromium-nickel steels after heating at temperatures between 1200 and 1500 F.

The etch tests have been carried on in conjunction with X-ray diffraction studies to identify the sigma phase and to ascertain how this constituent is revealed in metallographic examination through the use of a fairly large number of etchants. The results so far have varied somewhat when the different investigators used the same etchants on samples of steels heat treated under the same conditions. It is believed that the differences in the appearances of the sigma phase shown by the different investigators have been due to variations in etching technique, and during the past year additional samples have been investigated by the metallographers using identically the same etching procedures. These tests have been completed, and a progress report is being prepared for examination by the entire membership of Committee A-10. The intention is to have this report published after it has been studied by the main Committee.

Mr. F. B. Foley has been appointed secretary of Subcommittee VI.

Subcommittee VIII on Specifications for Wrought Products (R. B. Gunia, chairman) has under consideration a proposed specification for stainless steel strand wire. It is expected that work on this proposal will be completed during this year and a tentative specification issued.

There have been no changes made in other specifications under the jurisdiction of the subcommittee, but some action is indicated to remove specification A 276 from the tentative status. Certain sections of this specification are now under discussion, however, and it is possible that adoption of the specification as standard will not be accomplished for some time.

Subcommittee IX on Specifications for Flat Products (G. W. Hinkle, chairman) reports a favorable letter ballot on several changes in the chemical analysis of steels listed in Table I, Specification A 167 - 44. The proposed modifications will now be presented to Committee A-10 for approval by letter ballot.

This subcommittee is considering the inclusion of the low-carbon grades (0.03 per cent carbon max) in Specifications A 167 and A 240. As regards the inclusion of Type 316 plus Cb in specification A 240, a meeting will be arranged for the special subcommittee to discuss this question with the ASME Boiler Code subcommittee under Mr. Rossheim in the near future.

At the March, 1952, meeting in Cleveland, Subcommittee IX considered the suitability of the nitric acid test as applied to molybdenum and titanium-bearing austenitic stainless steels. This matter has been referred to Subcommittee IV for recommendation.

Subcommittee X on Specifications for Castings (J. J. Kanter, chairman).—The activities of this subcommittee during the past year have involved mainly the matter of specifications for cast tubular products. A task group under the chairmanship of W. F. Hodges has prepared a specification for centrifugally cast iron-chromium and iron-chromium-nickel alloy tubular products which was approved by Subcommittee X at the March 5, 1952 meeting in Cleveland, Ohio. This specification was subsequently submitted to letter ballot of the committee and the results will be reported at the Annual Meeting.

Subcommittee XI on Specifications for Tubular Products (J. J. B. Rutherford, chairman).—At a meeting of the Joint A-1, A-10 Subcommittee on Seamless Tubing Specifications held in Philadelphia on January 28, 1952, a recommendation was made to remove the requirements for passivation in Specifications A 213, A 249, A 269 and A 271.

There was considerable discussion, indicating general dissatisfaction, with the wording of the pink slip, Emergency Alternates. This particularly centered around the preliminary wording, "The following . . ., *when specified. . .*". Since this left the option entirely with the purchaser, the operation of these alternates became awkward and it was the consensus that a choice of wording could be selected to make the choice of the alternate more imperative.

There was some discussion on the subject on N.P.A. rulings concerning chemical composition of steels covered by ASTM specifications, for example TP-316 by N.P.A. ruling, molybdenum content changed to 1.75 to 2.50 per cent, whereas ASTM specifications are unchanged at 2.00 to 3.00 per cent.

This report has been submitted to letter ballot vote of the committee, which consists of 101 members; 92 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

M. A. CORDOVI,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-10 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Iron-Chromium and Iron-Chromium-Nickel Alloy Tubular Centrifugal Castings for General Applications (A 362 – 52 T).

Revision of Tentative Recommended Practice for:

Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 – 44 T).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the new and revised tentatives appear in the 1952 Book of ASTM Standards, Part 1.

REPORT OF COMMITTEE B-1
ON
WIRES FOR ELECTRICAL CONDUCTORS*

Committee B-1 on Wires for Electrical Conductors held three meetings during the year: one in New York, N. Y., on October 9, 1951; and two at the Society's Headquarters in Philadelphia, Pa., on January 11, 1952, and April 25, 1952. Meetings of Subcommittees IV, V, and VII also were held during the year.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. Halloran.
Vice-Chairman, W. R. Hibbard.
Secretary, A. A. Jones.

Election of members at large of the Advisory Committee resulted in the selection of the following: J. H. Foote, L. B. Curtis, R. H. Lloyd, A. A. DeFoe, and M. F. W. Heberlein.

The subcommittees' organization and their chairmen remain unchanged.

The committee notes with deep regret the passing in March, 1952, of Dr. Alan Morris, a former long-time member of the committee who contributed much to its work.

The committee now consists of 74 members, of whom 35 are classified as producers, 28 as consumers, and 11 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee B-1 presented to the Society through the Administrative Committee on Standards the recommendation that the Specifications for Standard Nominal Diameters and Cross-Sectional Areas of Awg Sizes of Solid Round Wires Used as Conductors be published as tentative. This recommendation was accepted by the Standards Committee on September 12, 1951, and the new tentative specifications appear in the 1951 Supplement to Book of ASTM Standards, Part 2, bearing the designation B 258 - 51 T.

NEW TENTATIVES

During the past few years there has been a growing consumer interest in steel-reinforced aluminum cable (ACSR) having steel core wires with heavier-than-standard zinc coatings (galvanizing) to provide increased corrosion resistance. The committee, therefore, recommends for publication as tentative the proposed Specifications for Zinc-Coated (Galvanized) Steel Core Wire (With Coatings Heavier than Standard Weight) for Aluminum Conductors, Steel Reinforced (ACSR) as appended hereto.[1]

Recent use of aluminum conductors in insulated products of the building wire class has indicated the need for conductors of a temper somewhat softer than hard drawn in order to provide additional ductility needed in making connections to terminal screws, etc. The committee, therefore, recommends for publication as tentative the proposed Specifications for Three-Quarter Hard Aluminum Wire for Electrical Purposes as appended hereto.[1]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 2.

REVISIONS OF TENTATIVES

The Committee recommends that the following seven specifications be revised as indicated and continued as tentative:

Tentative Specifications for Hard-Drawn Copper Wire (**B 1 - 51 T**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size,
(*2*) Wire size: diameter in inches (Section 4(*d*) and Table I),
(*3*) Type of copper, if special (Section 3),
(*4*) Whether certification of resistivity of rod stock is acceptable in lieu of resistivity tests on the finished wire (Section 6(*b*)),
(*5*) Package size (Section 9 (*a*)),
(*6*) Special package marking, if required, and
(*7*) Place of inspection (Section 5(*a*)).

Section 3(d).—Renumber as Section 4(*d*) and add, at the end of the second sentence, the words "expressed to the nearest 0.1 mil (0.0001 in.)."

Table I.—Add a footnote *c* to Table I reading as follows:

The tensile strength values in Table I apply only when the wire is drawn into coils of not less than 19 in. inside diameter and the wire has not been rewound. Lower values of tensile strength resulting from drawing the wire into smaller diameter coils, or rewinding, may be made applicable by mutual agreement between the manufacturer and the purchaser at the time the order is placed.

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (**B 172 - 51 T**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and class,
(*2*) Conductor size: circular-mil area or Awg (Section 7(*a*)),
(*3*) Class (Section 3 and Table I),
(*4*) Whether coated or uncoated; if coated, designate type of coating (Section 4 (*a*)),
(*5*) Details of special-purpose lays, if required (Section 6(*b*), 6(*c*), and Note 3),
(*6*) When physical tests shall be made (Section 8(*f*)),
(*7*) Package size (Section 12(*a*)),
(*8*) Special package marking, if required (Section 13),
(*9*) Lagging, if required (Section 12(*b*)), and
(*10*) Place of inspection (Section 14).

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (**B 173 - 51 T**):[2]

Section 2.—Revise as indicated above for Section 2 in Specifications B 172.

Tentative Specifications for Bunch-Stranded Copper Conductors for Electrical Conductors (**B 174 - 51 T**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and class,
(*2*) Conductor size: circular-mil area or Awg (Section 7(*a*)),
(*3*) Class (Section 3 and Table III),
(*4*) Whether coated or uncoated; if coated, designate type of coating (Section 4(*a*)),
(*5*) Maximum length of lay (Section 6(*c*) and Table II),
(*6*) Whether separator is required (Section 7(*b*)),
(*7*) When physical tests shall be made (Section 8(*f*)),

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[2] 1951 Supplement to Book of ASTM Standards, Part 2.

(*8*) Package size (Section 12(*a*)),
(*9*) Special package marking, if required (Section 13), and
(*10*) Place of inspection (Section 14).

Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (**B 230 – 50 T**).[3]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2 headed "Basis of Purchase," to read as follows:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity of each size,
> (*2*) Wire size: diameter in inches (Section 8(*a*) and Table I),
> (*3*) When tension tests on wires containing joints shall be made (Sections 5(*b*) and (*c*)),
> (*4*) Special jointing procedures, if permitted (Section 10(*b*)),
> (*5*) Package size (Section 12(*a*)),
> (*6*) Special package marking, if required, and
> (*7*) Place of inspection (Section 13).

Section 3.—Renumber as Section 4 and delete Paragraph (*a*).

Section 7(c).—Renumber to read Section *8(c)* and change the largest size range from "0.2100 to 0.1000, incl." to read "0.2600 to 0.1000, incl."

Table I.—Add another size range, as follows:

Diameter, in.	Tensile Strength, min, psi: Average for a Lot	Tensile Strength, min, psi: Individual Tests	Elongation in 10 in. for Individual Tests, min, per cent
0.2600 to 0.2101	23500	22500	2.2

Tentative Specifications for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (ACSR) (**B 232 – 50 T**).[3]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity of each size and stranding,
> (*2*) Conductor size: circular-mil area or Awg (Section 6 and Tables I or II),
> (*3*) Number of wires, aluminum and steel,
> (*4*) Direction of lay of outer layer of aluminum wires if other than right-hand (Section 5(*i*)),
> (*5*) Special tensile test, if required (Section 8(*b*)),
> (*6*) Package size (Section 12(*a*)),
> (*7*) Special package marking, if required (Section 13),
> (*8*) Lagging, if required (Section 12(*b*)), and
> (*9*) Place of inspection (Section 14).

Table I.—Revise as follows (values appearing in Table I and not indicated remain unchanged)

Conductor Size, cir mils: Present	Conductor Size, cir mils: Change to
105 500	105 600
66 370	66 360
52 640	52 620
33 100	33 090
26 250	26 240

Section 3(a).—Delete this paragraph.

Tentative Specifications for Standard Weight Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) (**B 245 – 49 T**).[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity of each size and type,
> (*2*) Wire size: diameter in inches (Section 7(*a*)),
> (*3*) Type (Section 1(*b*)),
> (*4*) Package size (Section 13(*a*)),
> (*5*) Special package marking, if required (Section 14), and
> (*6*) Place of inspection (Section 15).

Section 2(b).—Renumber to read Section *3(b)* and change the starting phrase from "The zinc used . . ." to read "The slab zinc when used. . . ."

Table I.—Change the nominal diameter size range from "0.1200 to 0.1890" to read "0.1200 to 0.1900, incl." Add

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[3] 1950 Supplement to Book of ASTM Standards, Part 2.

[4] 1949 Book of ASTM Standards, Part 2.

"incl." after 0.0899 and 0.1199 in other size ranges.

Table II.—Change the nominal diameter size range from "0.1200 to 0.190" to read "0.1200 to 0.1900, incl." Add "incl." after 0.0899 and 0.1199 in other size ranges.

Section 6.—Renumber as Section 7 and add a second sentence to Paragraph (*a*) reading "Expression of the nominal diameter of galvanized ACSR wire is in four decimals for the specific identification of certain steel wire sizes entering into the construction of individual conductors, and is not intended to imply that the wire shall be measured to four decimals for acceptance purposes."

TABLE I.—PERMISSIBLE VARIATIONS IN DIAMETER OF ZINC-COATED WIRE.

Nominal Diameter of Coated Wire, in.	Permissible Variation, in.	
	Plus	Minus
Under 0.0750	0.0015	0.001
0.0750 to 0.1199, incl	0.002	0.002
0.1200 to 0.1399, incl	0.003	0.002
0.1400 and over	0.004	0.003

NOTE.—It is recognized that the surface of heavy zinc coatings, particularly those produced by hot galvanizing, are not perfectly smooth and devoid of irregularities. If the tolerances shown above are rigidly applied to such irregularities that are inherent to the product, unjustified rejections of wire that would actually be satisfactory for use could occur. Therefore, it is intended that these tolerances be used in gaging the uniform areas of the galvanized wire.

Revise Paragraph (*b*) to read as follows:

(*b*) The average of two diameter readings, measured to the nearest 0.001 in., taken at right angles to each other, shall not differ from the specified diameter by more than the tolerances shown in Table III (accompanying Table I).

Tables III, IV and V.—Renumber as Tables IV, V, and VI.

Adoption of Tentative as Standard

Committee B-1 joins with Committees B-2 and B-5 in recommending the adoption as standard of the Tentative Classification of Coppers (ASTM Designation: B 224).[4]

Revision of Standards and Reversion to Tentatives

The committee recommends revision of the following three specifications as indicated and their reversion to tentative status.

Standard Specifications for Soft or Annealed Copper Wire (**B 3 – 45**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I),
(*3*) Type of copper, if special (Section 3),
(*4*) Package size (Section 10(*a*)),
(*5*) Special package marking, if required, and
(*6*) Place of inspection (Section 11).

Section 3(*c*).—Renumber as Section 4(*c*), and revise to read as follows:

(*c*) Tension tests shall be made on representative samples. The elongation of wire larger than 0.0201 in. shall be determined as the permanent increase in length, expressed in per cent of the original length, due to the breaking of the wire in tension, measured between gage marks placed originally 10 in. apart upon the test specimen (Note 4). The elongation of wire 0.0201 in. and under in diameter may be determined as described above or by measurements made between the jaws of the testing machine. When the latter method is used, the zero length shall be the distance between the jaws at the start of the tension test and be as near 10 in. as practicable and the final length shall be the distance between the jaws at the time of rupture. The fracture shall be between gage marks in the case of specimens so marked or between the jaws of the testing machine and not closer than 1 in. to either gage mark or either jaw.

Section 5.—Renumber as Section 6 and revise Paragraph (*a*) to read as follows:

(*a*) The wire sizes shall be expressed as the diameter of the wire in decimal fractions of an inch to the nearest 0.1 mil (0.0001 in.) (Note 2).

In the table of Paragraph (*b*) add a footnote referenced after "1 per cent" to read "Expressed to the nearest 0.1 mil (0.0001 in.)."

TABLE II.—REVISED VALUES FOR TABLE I OF SPECIFICATIONS B 3.

Diameter, in.		Area at 20 C (68 F)			
		cir mils		sq in.	
Present	Change to	Present	Change to	Present	Change to
...	...	105 500	105 600	0.08289	0.08291
...	...	66 370	66 360	0.05213	0.05212
...	...	52 640	52 620	0.04134	0.04133
...	...	33 100	33 090	0.02600	0.02599
...	...	26 250	26 240	0.02062	0.02061
0.09074	0.0907	8 234	8 230	0.006467	0.00646
0.08081	0.0808	...	...	0.005129	0.00513
0.07196	0.0720	5 178	5 180	0.004067	0.00407
0.06408	0.0641	4 107	4 110	0.003225	0.00323
0.05707	0.0571	3 257	3 260	0.002558	0.00256
0.05082	0.0508	2 583	2 580	0.002028	0.00203
0.04526	0.0453	2 048	2 050	0.001609	0.00161
0.04030	0.0403	1 624	1 620	0.001276	0.00128
0.03589	0.0359	1 288	1 290	0.001012	0.00101
0.03196	0.0320	1 022	1 020	0.0008023	0.000804
0.02846	0.0285	810.1	812	0.0006363	0.000638
0.02535	0.0253	642.4	640	0.0005046	0.000503
0.02257	0.0226	509.5	511	0.0004001	0.000401
0.02010	0.0201	404.0	404	0.0003173	0.000317
0.01790	0.0179	320.4	320	0.0002517	0.000252
0.01594	0.0159	254.1	253	0.0001996	0.000199
0.01420	0.0142	201.5	202	0.0001583	0.000158
0.01264	0.0126	159.8	159	0.0001255	0.000125
0.01126	0.0113	126.7	128	0.00009954	0.000100
0.01003	0.0100	100.5	100	0.00007894	0.0000785
0.008928	0.0089	79.70	79.2	0.00006260	0.0000622
0.007950	0.0080	63.21	64.0	0.00004964	0.0000503
0.007080	0.0071	50.13	50.4	0.00003937	0.0000396
0.006305	0.0063	39.75	39.7	0.00003122	0.0000312
0.005615	0.0056	31.52	31.4	0.00002476	0.0000246
0.005000	0.0050	25.00	25.0	0.00001963	0.0000196
0.004453	0.0045	19.83	20.2	0.00001557	0.0000159
0.003965	0.0040	15.72	16.0	0.00001235	0.0000126
0.003531	0.0035	12.47	12.2	0.000009793	0.00000962
0.003145	0.0031	9.888	9.61	0.000007766	0.00000755

Table I.—Revise as indicated in the accompanying Table II (values appearing in Table I and not indicated remain unchanged.)

Explanatory Note 2.—Revise to read as follows:

NOTE 2.—The values of the wire diameters in Table I are given to the nearest 0.0001 in. and correspond to the standard sizes given in the Tentative Specifications for Standard Nominal Diameters and Cross-Sectional Areas of Awg Sizes of Solid Round Wires Used as Electrical Conductors (ASTM Designation: B 258). The use of gage numbers to specify wire sizes is not recognized in these specifications because of the possibility of confusion. An excellent discussion of wire gages and related subjects is contained in *Circular No. 31* of the National Bureau of Standards.

Standard Specifications for Tinned Soft or Annealed Copper Wire for Electrical Purposes (**B 33 – 51**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under this specification shall include the following information:

(*1*) Quantity of each size,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I),
(*3*) Type of copper, if special (Section 3(*b*)),
(*4*) Package size (Section 15(*a*)),
(*5*) Special package marking, if required, and
(*6*) Place of inspection (Section 16).

Section 3(c).—Renumber to read Section 4(*c*), and revise as indicated above for Section 3(*c*) in Specifications B 3.

Section 5(a).—Renumber to read Section 6(*a*), and revise to read "The wire sizes shall be expressed as the diameter of the wire in decimal fractions of an inch to the nearest 0.1 mil (0.0001 in.) (Note 2)."

Table I.—Revise as indicated above for Table I in Specifications B 3.

Table III.—Add a footnote referenced after "3 per cent" and "1 per cent" to read "Expressed to the nearest 0.1 mil (0.0001 in.)."

Explanatory Note 2.—Revise as indicated above for Explanatory Note 2 of Specifications B 3.

Standard Specifications for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes (**B 189 - 51**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size and type of coating,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I),
(*3*) Type of coating (Section 1),
(*4*) Type of copper, if special (Section 3(*b*)),
(*5*) Package size (Section 13(*a*)),
(*6*) Special package marking, if required, and
(*7*) Place of inspection (Section 14).

Section 3(c).—Renumber to read Section 4(*c*), and revise as indicated above for Section 3(*c*) in Specifications B 3.

Section 5.—Renumber as Section 6 and revise Paragraph (*a*) to read "The wire sizes shall be expressed as the diameter of the wire in decimal fractions of an inch to the nearest 0.1 mil (0.0001 in.) (Note 1)."

In the table of Paragraph (*b*) add a footnote referenced after "3 per cent" and "1 per cent" to read "Expressed to the nearest 0.1 mil (0.0001 in.)."

Table I.—Revise as indicated above for Table I in Specifications B 3.

Explanatory Note 1.—Revise as indicated above for Explanatory Note 2 of Specifications B 3.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends, for immediate adoption, revisions in the following 14 standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Medium-Hard-Drawn Copper Wire (**B 2 - 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I),
(*3*) Type of copper, if special (Section 3),
(*4*) Package size (Section 10(*a*)),
(*5*) Special package marking, if required, and
(*6*) Place of inspection (Section 11).

Section 5.—Renumber to read Section 6 and revise Paragraph (*a*) to read "The wire sizes shall be expressed as the diameter of the wire in decimal fractions of an inch to the nearest 0.1 mil (0.0001 in.) (Note 2)."

In Paragraph (*b*) add at the end of the present text "expressed to the nearest 0.1 mil (0.0001 in.)"

Table I.—Revise as indicated in the accompanying Table III (values appearing in Table I and not indicated remain unchanged).

Explanatory Note 2.—Revise as indicated above for Explanatory Note 2 of Specifications B 3.

TABLE III.—REVISED VALUES FOR TABLE I OF SPECIFICATIONS B 2.

Diameter, in.		Area at 20 C (68 F)			
		cir mils		sq in.	
Present	Change to	Present	Change to	Present	Change to
...	...	105 500	105 600	0.08289	0.08291
...	...	66 370	66 360	0.05213	0.05212
...	...	52 640	52 620	0.04134	0.04133
...	...	33 100	33 090	0.02600	0.02599
...	...	26 250	26 240	0.02062	0.02061
0.09074	0.0907	8 234	8 230	0.006467	0.00646
0.08081	0.0808	...	...	0.005129	0.00513
0.07196	0.0720	5 178	5 180	0.004067	0.00407
0.06408	0.0641	4 107	4 110	0.003225	0.00323
0.05707	0.0571	3 257	3 260	0.002558	0.00256
0.05082	0.0508	2 583	2 580	0.002028	0.00203
0.04526	0.0453	2 048	2 050	0.001609	0.00161
0.04030	0.0403	1 624	1 620	0.001276	0.00128

Standard Specifications for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (**B 8 - 50**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size and class,
(*2*) Conductor size: circular-mil area or Awg (Section 6),
(*3*) Class (Section 1(*b*) and Table II),
(*4*) Temper (Section 3(*b*)),
(*5*) Whether coated or uncoated; if coated, designate type of coating (Sections 3(*a*) and (*b*)),
(*6*) Details of special-purpose lays, if required (Section 5(*d*)),
(*7*) When physical tests shall be made (Sections 7(*f*), 8(*b*) and 8(*c*)),
(*8*) Package size (Section 12(*a*)),
(*9*) Lagging, if required (Section 12(*b*)),
(*10*) Special package marking, if required (Section 13), and
(*11*) Place of inspection (Section 14).

Table II.—Revise as indicated in the accompanying Table IV (values appearing in Table II and not indicated remain unchanged).

TABLE IV.—REVISED VALUES FOR TABLE II OF SPECIFICATIONS B 8.

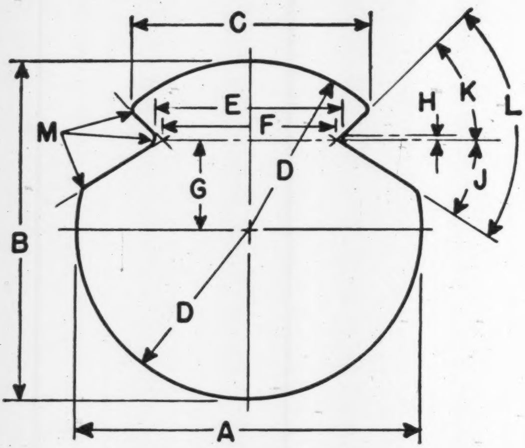
Area of Cross-Section, cir mils	
Present	Change to
105 500	105 600
66 370	66 360
52 640	52 620
33 100	33 090
26 250	26 240
4 107	4 110
2 583	2 580
1 624	1 620
1 022	1 020

Standard Specifications for Bronze Trolley Wire (**B 9 - 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size, section, and class,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I) or area in circular mils (Section 10(*a*) and Fig. 1),
(*3*) Shape of section (Section 1(*a*)),
(*4*) Class of bronze (Section 1(*b*) and Note 1),
(*5*) Package size (Section 15(*c*)),
(*6*) Lagging, if required (Section 15(*a*)),
(*7*) Relation between vertical axis of grooved wire and axis of reel (Section 15(*a*)),
(*8*) Size of arbor hole if other than 4 in. square (Section 15(*b*)),
(*9*) Special package marking, if required (Section 15(*d*)), and
(*10*) Place of inspection (Section 16).



NOTE.—Dimension H is defined by two center lines, of which the upper is the center line of the radius of the groove, and the lower is the center line of the groove.

Nominal Size, cir. mils.	133 200	168 100	211 600	300 000	350 000
Area, sq. in. (Note 8)	0.1083	0.1314	0.1665	0.2355	0.2758
Area, cir. mils (Note 8)	137 900	167 300	212 000	299 800	351 200
Weight, lb. per Mile (Note 8)	2205	2674	3389	4792	5612
DIMENSIONS FOR INSPECTION, IN.					
A	$0.388\ {}^{+0.006}_{-0.012}$	$0.429\ {}^{+0.006}_{-0.012}$	$0.482\ {}^{+0.006}_{-0.012}$	$0.574\ {}^{+0.010}_{-0.020}$	$0.620\ {}^{+0.010}_{-0.020}$
B	0.392 ± 0.007	0.430 ± 0.008	0.482 ± 0.009	0.574 ± 0.011	0.620 ± 0.012
DIMENSIONS FOR REFERENCE, IN.					
C	0.318 ± 0.007	0.340 ± 0.007	0.376 ± 0.007	0.376 ± 0.007	0.376 ± 0.007
D—Radius	0.196	0.215	0.241	0.287	0.310
E	$0.217\ {}^{+0.005}_{-0.010}$	$0.237\ {}^{+0.005}_{-0.010}$	0.267 ± 0.010	0.267 ± 0.010	0.267 ± 0.010
F	0.200	0.220	0.250	0.250	0.250
G	0.031	0.047	0.063	0.127	0.156
H	0.005	0.005	0.005	0.005	0.005
J	27 ± 2 deg.	27 ± 2 deg.	27 ± 2 deg.	27 ± 2 deg.	27 ± 2 deg.
K	51 ± 2 deg.	51 ± 2 deg.	51 ± 2 deg.	51 ± 2 deg.	51 ± 2 deg.
L	78 deg.	78 deg.	78 deg.	78 deg.	78 deg.
M—Radius	$0.015\ {}^{+0.010}_{-0.005}$	$0.015\ {}^{+0.010}_{-0.005}$	$0.015\ {}^{+0.010}_{-0.005}$	$0.015\ {}^{+0.010}_{-0.005}$	$0.015\ {}^{+0.010}_{-0.005}$

FIG. 1.—Slip Gage for Testing Groove of Trolley Wire (Specifications B 9 and B 47).

Appendix.—Add as an Appendix, the following:

The following changes are under consideration by Committee B-1 to cover the use of a gage for checking the dimensions of grooved trolley wire and include the proposed dimensions of the gage. They are presented for consideration and experimental purposes only. The required dimensions of the gage as indicated are subject to possible revision during the process of experimentation with the gage. When experience indicates that the gage is a satisfactory means for control of trolley wire sizes, it is proposed to offer for incorporation in the specifications the following changes.

Section 10(c).—Revise to read as follows:

(*c*) Conformance of the trolley wire to the specified dimensions shall be determined by taking the measurements shown in Fig. 1 under the heading, "Dimensions for Inspection, In."

The shape of the groove shall be checked with the appropriate "go," "no go" slip gages described in Fig. 2 (accompanying Fig. 1). The gages shall be applied to the ends of the samples taken from each reel. The groove shall comply with these specifications if the go gage can be pushed on the straightened wire by hand and the no go gage cannot be pushed on the wire.

Fig. 1.—Remove dimension "C" in Fig. 1 from table of "Dimensions for Reference" and add to the table of "Dimensions for Inspection."

New Figure.—Add a new Fig. 2 as shown in the accompanying Fig. 1.

Explanatory Note 7.—Delete Note 7 and renumber Note 8 as Note 7.

Standard Specifications for Copper Trolley Wire (**B 47 – 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and section,
(*2*) Wire size: diameter in inches (Section 6(*a*) and Table I) or area in circular mils (Section 10(*a*) and Fig. 1),
(*3*) Shape of section (Section 1),
(*4*) Type of copper, if special (Section 3),
(*5*) Package size (Section 15(*c*)),
(*6*) Lagging, if required (Section 15(*a*)),
(*7*) Relation between vertical axis of grooved wire and axis of reel (Section 15(*a*)),
(*8*) Size of arbor hole, if special (Section 15(*b*)),
(*9*) Special package marking, if required (Section 15(*d*)), and
(*10*) Place of inspection (Section 16).

Appendix.—Add as an Appendix the following:

The following changes are under consideration by Committee B-1 to cover the use of a gage for checking the dimensions of grooved trolley wire and include the proposed dimensions of the gage. They are presented for consideration and experimental purposes only. The required dimensions of the gage as indicated are subject to possible revision during the process of experimentation with the gage. When experience indicates that the gage is a satisfactory means for control of trolley wire sizes, it is proposed to offer for incorporation in the specifications the following changes.

Section 10(c).—Revise to read as follows:

Conformance of the trolley wire to the specified dimensions shall be determined by taking the measurements shown in Fig. 1 under the heading, "Dimensions for Inspection, in."

The shape of the groove shall be checked with the appropriate "go," "no go" slip gages described in Fig. 2 (accompanying Fig. 1). The gages shall be applied to the ends of the samples taken from each reel. The groove shall comply with these specifications if the go gage can be pushed on the straightened wire by hand and the no go gage cannot be pushed on the wire.

Fig. 1.—Remove dimension "C" in Fig. 1 from table of "Dimensions for Reference" and add to the table of "Dimensions for Inspection."

New Figure.—Add a new Fig. 2 as shown in the accompanying Fig. 1.

Explanatory Note 4.—Delete Note 4 and renumber Note 5 as Note 4.

Standard Specifications for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (**B 48 – 51**):[2]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size, section and type,
(*2*) Type of wire and shape (Sections 2(*a*) and (*b*)),
(*3*) Wire size: thickness and width, in inches (Section 8(*a*)),
(*4*) Type of copper, if special (Section 3),
(*5*) Package size (Section 11(*a*)),
(*6*) Special package marking, if required, and
(*7*) Place of inspection (Section 12).

Note 7.—Revise by deleting the words in brackets:

NOTE 7.—Table II gives data on cross-sectional area of square wire in sizes 0.0508 to 0.4600 in., inclusive, allowance having been made for reduction of the theoretical area of a perfect square wire due to the rounding of its four corners as shown in Table I of these specifications. These areas are for the nominal dimensions shown in column 1 of Table II and do not take into account the variations in the dimensions of an actual wire as permitted by the tolerances given in these specifications. [It has been demonstrated that there is no practical need for expressing working net areas to the same large number of significant figures given, as for instance, in columns 2 or 3. It is felt that] the significance of these working net area values should not extend beyond the significance of the values in column 1 and it is for this reason that the working net area values have been rounded off as shown in column 7.... Other information (circular mil area, weight and resistance) often found necessary, can be derived from the data given in Table II as follows:

Note 8.—Revise by deleting the words in brackets, and adding the italicized words.

NOTE 8.—Table III gives the calculated area in square mils to be deducted, because of the rounding of the four corners of the rectangular wire from the area of a circumscribing rectangle having the same thickness and width, in order to obtain the working net area of the wire. The areas to be deducted are based on the radii specified in Table I of these specifications, and do not take into account probable increase or decrease of the area of an actual wire due to the variation in its dimensions within the limits of the tolerances given in these specifications—as in the case of square, [it has been demonstrated that there in no practical need for expressing] working net areas of rectangular wire ***should not extend*** to a number of significant figures greater than that employed in specifying its thickness and width. This is also true of any other derived values such as circular mil area, weight or electrical resistance.

Standard Specifications for Hot-Rolled Copper Rods for Electrical Purposes **(B 49 - 50)**:[3]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and finish,
(*2*) Rod size: diameter in inches (Section 7 and Table I),
(*3*) Finish (Section 9(*a*)),
(*4*) Type of copper, if special (Section 3),
(*5*) Package size (Section 10),
(*6*) Special package marking, if required, and
(*7*) Place of inspection (Section 11).

Standard Specifications for Hard-Drawn Copper Alloy Wires for Electrical Conductors **(B 105 - 49)**:[4]

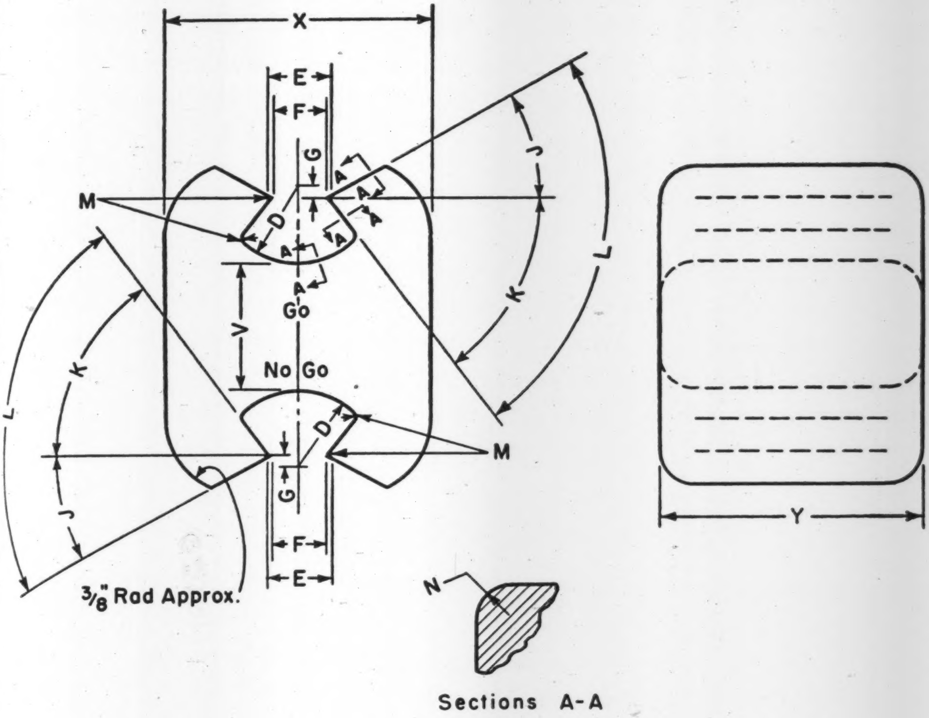
Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

TABLE V.—REVISED VALUES FOR TABLE I OF SPECIFICATIONS B 105.

Diameter, in.		Area at 20 C (68 F)			
		cir mils		sq in.	
Present	Change to	Present	Change to	Present	Change to
...	...	66 370	66 360	0.05213	0.05212
...	...	52 640	52 620	0.04134	0.04133
...	...	33 100	33 090	0.02600	0.02599
...	...	26 250	26 240	0.02062	0.02061
0.09074	0.0907	8 234	8 230	0.006467	0.00646
0.08081	0.0808	...	...	0.005129	0.00513
0.07196	0.0720	5 178	5 180	0.004067	0.00407
0.06408	0.0641	4 107	4 110	0.003225	0.00323
0.05707	0.0571	3 257	3 260	0.002558	0.00256
0.05082	0.0508	2 583	2 580	0.002028	0.00203
0.04526	0.0453	2 048	2 050	0.001609	0.00161
0.04030	0.0403	1 624	1 620	0.001276	0.00128
0.03589	0.0359	1 288	1 290	0.001012	0.00101
0.03196	0.0320	1 022	1 020	0.0008023	0.000804

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and grade,
(*2*) Wire size: diameter in inches (Section 8(*a*) and Table I),
(*3*) Grade number (Section 1(*b*) and Table I),
(*4*) Special composition limits, if required (Section 4(*b*)),
(*5*) Package size (Section 12(*a*)),
(*6*) Special package marking, if required, and
(*7*) Place of inspection (Section 13).

Section 7.—Renumber as Section 8 and revise as indicated above for Section 5 of Specifications B 189 except refer to Note 2 instead of Note 1 at end of paragraph (*a*).



Dimension	Dimensions of Gage, in. (Except as Indicated)	
	For Trolley Wire of Nominal Sizes, 350,000 and 400,000 cir mil	
	Go	No Go
D	5/16	5/16
E	0.278 ± 0.0005	$0.257^{+0.000}_{-0.001}$
F	0.268	0.248
G	0.063	0.063
J	25 deg	29 deg
K	53 deg	53 deg
L	78 deg	82 deg
M—Radius	0.010 ± 0.002	0.010 ± 0.002
N—Radius	1/16	1/16
V	1/2	1/2
X	1	1
Y	1	1

FIG. 2.—Slip Gage for Testing Groove of Trolley Wire (Specifications B 116).

Table I.—Revise as indicated in the accompanying Table V (values appearing in Table I and not indicated remain unchanged).

Explanatory Note 2.—Revise as indicated above for Explanatory Note 2 of Specifications B 3.

Standard Specifications for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (**B 116 – 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specificaons shall include the following information:

(*1*) Quantity of each size and section,
(*2*) Wire size: circular-mil area (Section 6, Figs. 1 or 2),
(*3*) Shape of section (Section 1),
(*4*) Type of copper, if special (Section 3),
(*5*) Package size (Section 11(*c*)),
(*6*) Lagging, if required (Section 11(*a*)),
(*7*) Relation between vertical axis of grooved wire and axis of reel (Section 11(*a*)),
(*8*) Size of arbor hole if other than for a $2\frac{1}{2}$-in. shaft (Section 11(*b*)),
(*9*) Special package marking, if required (Section 11(*d*)), and
(*10*) Place of inspection (Section 12).

Appendix.—Add as an Appendix the following:

The following changes are under consideration by Committee B-1 to cover the use of a gage for checking the dimensions of grooved trolley wire and include the proposed dimensions of the gage. They are presented for consideration and experimental purposes only. The required dimensions of the gage as indicated are subject to possible revision during the process of experimentation with the gage. When experience indicates that the gage is a satisfactory means for control of trolley wire sizes, it is proposed to offer for incorporation in the specifications the following changes.

Section 5(*e*).—Revise to read as follows:

Conformance of the trolley wire to the specified dimensions shall be determined by taking the measurements shown in Figures 1 and 2 under heading, "Dimensions for Inspection, in."

The shape of the groove for figure-9 trolley wire shall be checked with the "go," "no go" slip gages described in Fig. 3. The gages shall be applied to the ends of the samples taken from each reel. The groove shall comply with these specifications if the go gage can be pushed on the straightened wire by hand and the no go gage cannot be pushed on the wire.

Fig. 2.—Remove dimension "C" in Fig. 2 from table of "Dimensions for Reference" and add to the table of "Dimensions for Inspection."

New Figure.—Add a new Fig. 3 as shown in the accompanying Fig. 2.

Note 5.—Delete Note 5 and renumber Note 6 as Note 5.

Standard Specifications for Cored, Annular, Concentric-Lay-Stranded Copper Conductors (**B 226 – 50**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2 headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size,
(*2*) Conductor size: circular-mil area (Section 7 and Table I),
(*3*) Whether coated or uncoated, if coated, designate type of coating (Section 4),
(*4*) Specific kind and treatment of core material (Section 3),
(*5*) Details of special-purpose lays, if required (Sections 6(*a*) and (*b*) and Note 3),
(*6*) Package size (Section 12),
(*7*) Lagging, if required (Section 12(*b*)),
(*8*) Special package marking, if required (Section 13), and
(*9*) Place of inspection (Section 14).

TABLE VI.—REVISED VALUES FOR TABLE I OF SPECIFICATIONS B 227.

Area at 20 C (68 F)			
cir mils		sq in.	
Present	Change to	Present	Change to
33 100	33 090	0.02600	0.02599
26 250	26 240	0.02062	0.02061

Standard Specifications for Hard-Drawn Copper Covered Steel Wire (**B 227 – 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity of each size and grade,
(*2*) Wire size: diameter in inches (Section 7(*a*) and Table I),

(*3*) Grade (Section 1(*b*) and Table I),
(*4*) Method of measuring elongation (Sections 5(*c*) and 5(*d*)),
(*5*) Package size (Section 14(*a*)),
(*6*) Special package marking, if required (Section 13), and
(*7*) Place of inspection (Section 15).

Table I.—Revise as indicated in the accompanying Table VI (values appearing in Table I and not indicated remain unchanged).

Explanatory Note 3.—Revise to read as follows:

NOTE 3.—The values of the wire diameters in Table I are given to the nearest 0.0001 in. and correspond to the standard sizes given in tne Tentative Specifications for Standard Nominal Diameters and Cross-Sectional Areas of Awg Sizes of Solid Round Wires Used as Electrical Conductors (ASTM Designation: B 258). The diameters preceded by asterisks are not in the American Wire Gage series and are also given to four places of decimals. They correspond to certain of the numbers of the Birmingham Wire Gage or of the British Standard Wire Gage and are used for communication lines. The use of gage numbers in specifiying wire sizes is not recognized in these specifications because of the possibility of confusion. An excellent discussion of wire gages and related subjects is contained in *Circular No. 31* of the National Bureau of Standards.

TABLE VII.—REVISED VALUES FOR TABLES I AND IV OF SPECIFICATIONS B 229.

Conductor Size, Hard-Drawn Copper Equivalent, cir mils	
Present	Change to
105 500	105 600
66 370	66 360
52 630	52 620
33 100	33 090
26 250	26 240

Standard Specifications for Concentric-Lay-Stranded Copper Covered Steel Conductors (**B 228 – 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and grade,
(*2*) Conductor size: approximate diameter in fractions of an inch, or number and Awg size of individual wires (Section 6 and Table I),
(*3*) Grade (Section 1(*b*) and Table I),
(*4*) Direction of lay of outer layer, if other than left-hand (Section 5(*c*)),
(*5*) When physical tests shall be made (Section 7(*b*)),
(*6*) Package size (Section 11(*a*)),
(*7*) Special package marking, if required (Section 12),
(*8*) Lagging, if required (Section 11(*b*)), and
(*9*) Place of inspection (Section 13).

TABLE VIII.—REVISED VALUES FOR TABLE II OF SPECIFICATIONS B 231.

Conductor Size, cir mils	
Present	Change to
105 500	105 600
66 370	66 360
52 640	52 620
33 100	33 090
26 250	26 240
4 107	4 110
2 583	2 580
1 624	1 620
1 022	1 020

Standard Specifications for Concentric-Lay-Stranded Copper and Copper Covered Steel Composite Conductors (**B 229– 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and type,
(*2*) Conductor size: hard-drawn copper equivalent in circular-mil area or Awg (Section 6 and Table I),
(*3*) Type (Section 1(*b*), Fig. 1, and Table I),
(*4*) Direction of lay of outer layer, if other than left-hand (Section 5(*c*)),
(*5*) When physical tests shall be made (Section 7(*b*)),

(*6*) Package size (Section 12(*a*)),
(*7*) Special package marking, if required (Section 13),
(*8*) Lagging, if required (Section 12(*b*)), and
(*9*) Place of inspection (Section 14).

Tables I and IV.—Revise as indicated in the accompanying Table VII (values appearing in Tables I and IV and not indicated remain unchanged).

Standard Specifications for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (**B 231 – 49**):[4]

Section 2.—Renumber the present Section 2 to read Section 3 and renumber all following sections accordingly. Insert a new Section 2, headed "Basis of Purchase," to read as follows:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity of each size and class,
(*2*) Conductor size: circular-mil area or Awg (Section 6 and Table II),
(*3*) Class (Section 1(*b*)),
(*4*) Details of special-purpose lays, when required (Sections 5(*b*), 5(*c*), 5(*d*), and 5(*e*)),
(*5*) When physical tests shall be made (Sections 7(*b*) and 7(*c*)),
(*6*) Package size (Section 11(*a*)),
(*7*) Special package marking, if required (Section 12),
(*8*) Lagging, if required (Section 11(*b*)), and
(*9*) Place of inspection (Section 13).

Table II.—Revise as indicated in the accompanying Table VIII (values appearing in Table II and not indicated remain unchanged).

Standard Specifications for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (**B 233 – 49**):[4]

Section 1(b).—Revise to read as follows:

(*b*) Five types of rods are covered by these specifications, designated as follows:
Type EC – H 16
Type EC – H 14
Type EC – H 12
Type EC – 0
Type EC – H 12 – B

Section 2.—Revise to read as follows:

2. (*a*) Orders for material under these specifications shall include the following information:
(*1*) Quantity of each type,
(*2*) Type of rod (Section 1(*b*) and Table I),
(*3*) Whether or not joints are permitted (Section 3(*a*)),
(*4*) Elongation tests, if required (Section 4(*d*)),
(*5*) Package size (Section 11(*b*)),
(*6*) Special package marking, if required (Section 11(*d*)), and
(*7*) Place of inspection (Section 12).

(*b*) The selection of the type of rod should be made in consideration of the size of wire to be produced (Note 1).

Sections 4, 5, and 6.—Delete and renumber all subsequent sections accordingly.

Section 7(a).—Renumber to read Section 4(*a*) and revise to read "The tensile strength of the respective types of rod shall conform to the requirements prescribed in Table I (Note 1)."

Table II.—Renumber as Table I with the title "Tensile Requirements." Add another type of rod between H 16 and H 12 as follows:

Type	Tensile Strength, psi
EC – H 14	14 000 to 20 000

Note 1.—Renumber as Note 2 and renumber all following notes accordingly. Insert a new Note 1 as follows:

NOTE 1.—Wire drawing mill practices vary as to the sizes of wire produced from the various types of hot-rolled rod. For information, one typical practice is as shown in Table II.

Table I.—Renumber as Table II with the title "Type of Rod to Produce Various Finished Wire Diameters," and move table into Explanatory Notes to accompany Note 1. Add another type of rod between H 16 and H 12 as follows:

Type	Finished Wire Diameter, in.
EC – H 14	0.1350 to 0.2100

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Editorial and Records (A. A. Jones, Chairman) continued its editorial review of specifications and coordinated the various subcommittee recommendations regarding "Basis of Purchase" sections for product specifications.

Subcommittee II on Methods of Test and Sampling Procedure (J. B. Dixon, Chairman) completed preparation of the proposed method for determination of cross-sectional area, is collecting data on tensile strength and elongation of soft copper wire to be used as a basis for revision of Specifications B 3, and is considering the desirability of ultimately developing statistical sampling procedures for hard-drawn aluminum wire.

Subcommittee IV on Conductors of Copper and Copper Alloys (B. J. Sirois, Chairman) completed preparation of the tentative specifications covering the American Wire Gage and has developed the "go", "no go" gage for inspection testing of grooved trolley wire to the point where it is recommended for inclusion in appendices to the trolley wire specifications in order to gain experience data.

Task groups are considering the addition of a 55 per cent conductivity alloy for bronze trolley wire, the addition of figure 9 deep-section bronze trolley wire, and stiffness test requirements for magnet wire.

Subcommittee V on Conductors of Ferrous Metals (L. H. Winkler, Chairman) completed the revision of Specifications B 245 for steel core wire (for ACSR) having standard zinc coating and completed preparation of the proposed specifications for steel core wire having heavier-than-standard zinc coating.

Subcommittee VI on Composite Conductors of Copper and Steel (C. E. Ambelang, Chairman) is considering the need for specifications for annealed copper covered steel wire.

Subcommittee VII on Conductors of Light Metals (P. V. Faragher, Chairman) completed preparation of the proposed specification for three-quarter hard aluminum wire, is working on the preparation of a specification for annealed or one-quarter hard aluminum wire suitable for telephone cable applications, and is considering the development of specifications for aluminum wire to be used in magnet wire.

This report has been submitted to letter ballot of the committee, which consists of 74 members; 36 members returned their ballots, of whom 35 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

D. HALLORAN,
Chairman.

A. A. JONES,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members for Electrical Conductors (B 172 - 51 T),
Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors (B 173 - 51 T), and
Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 - 51 T).

These recommendations were accepted by the Standards Committee on August 1, 1952, and the revised specifications appear in the 1952 Book of ASTM Standards, Part 2.

REPORT OF COMMITTEE B-2
ON
NON-FERROUS METALS AND ALLOYS*

Committee B-2 on Non-Ferrous Metals and Alloys has held no meeting since the Annual Meeting in Atlantic City, N. J., on Tuesday, June 19, 1951. During the past year, the committee has handled all its work by correspondence.

The following three subcommittees have work before their respective task groups, namely, Subcommittee III on White Metal Alloys, Subcommittee VI on Coated Metals, and Subcommittee VIII on Miscellaneous Refined Metals and Alloys. At present there is no actual work before the other subcommittees, although certain plans have been made which will place work before some of them prior to the end of 1952.

At the Annual Meeting on June 19, 1952 the committee confirmed the nomination of and elected to Honorary Membership in Committee B-2 Mr. R. H. Leach and Mr. George O. Hiers. Certificates of Honorary Membership have been sent to both these gentlemen by the Secretary of the committee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Bruce W. Gonser.
Secretary, G. Howard LeFevre.

The Advisory Committee met on June 19, 1951 in Atlantic City, N. J., and again on March 11, 1952, in New York City, N. Y. At this time the committee has the following recommendations in connection with standards under its jurisdiction: the standards appear in their present form in the 1949 Book of ASTM Standards, Part 2.

New Tentatives

Committee B-2 recommends for immediate adoption the following proposed specification as appended hereto:[1]

Tentative Specifications for:

Iodide Titanium,
Titanium Strip, Sheet, Plate, Bar, Tube, Rod and Wire, and
Titanium Ingot

Adoption of Tentatives as Standard

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Metallic Antimony (B 237 – 49 T), and
Classification of Coppers (B 224 – 48 T).

Reaffirmation of Standards

The committee recommends reaffirmation of the following standards which have been published for six years or longer without revision.

Standard Specifications for:

Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5 – 43),
Electrolytic Cathode Copper (B 115 – 43),
Rolled Zinc (B 69 – 39),
Lead-Coated Copper Sheets (B 101 – 40), and
Nickel (B 39 – 22).

Tentatives Continued Without Revision

The committee recommends that the following tentatives be continued as tentative without revision:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 2.

Tentative Specifications for:

Nickel-Copper Alloys Plate, Sheet and Strip (B 127 – 49 T),
Nickel Rods and Bars (B 160 – 49 T),
Nickel Seamless Pipe and Tubing (B 161 – 49 T),
Nickel Plate, Sheet and Strip (B 162 – 49 T),
Seamless Nickel and High Nickel Alloy Condenser, Evaporator and Heat-Exchanger Tubes (B 163 – 49 T),
Nickel-Copper Alloy Rods and Bars (B 164 – 49 T),
Nickel-Copper Alloy Seamless Pipe and Tubing (B 165 – 49 T),
Nickel-Chromium-Iron Alloy Rods and Bars (B 166 – 49 T), and
Nickel-Chromium-Iron Alloy Plate, Sheet and Strip (B 168 – 49 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Refined Lead, Tin, Antimony and Bismuth (Sidney Rolle, chairman).—Following a poll of the subcommittee as to the advisability at this time of issuing a proposed tentative specification for pig tin, in the light of the results of this poll and by action of the Advisory Committee, the proposed tentative specification will not be submitted to letter ballot until the Advisory Committee gives further consideration to the question on or before March, 1953.

Subcommittee III on White Metals and Alloys (Dr. G. H. Clamer, chairman).—The task group on Cored Solder Wire is working on a proposed tentative specification.

Subcommittee VI on Coated Metals (F. L. Scovill, Jr., chairman).—The subcommittee continues the study, which has been in progress over the past two years, of methods of test for continuity of coating for inclusion in the Standard Specifications for Lead-Coated Copper Sheets (B 101 – 40).

Subcommittee VII on Refined Nickel and Cobalt, High Nickel Alloys and High Cobalt Alloys, Cast and Wrought (O. B. J. Fraser, chairman) is preparing specifications covering Hastelloy "B", and together with a group from Committee A-10, Hastelloy "C".

Subcommittee VIII on Miscellaneous Refined Metals and Alloys (E. E. Schumacher, chairman) recommends for adoption the three appended proposed tentative specifications for titanium.

This report has been submitted to letter ballot of the committee, which consists of 131 members; 77 members returned their ballots, of whom 76 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

BRUCE W. GONSER,
Chairman.

G. HOWARD LEFEVRE,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE B-3

ON

CORROSION OF NON-FERROUS METALS AND ALLOYS*

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held a meeting in Atlantic City, N. J., on June 21, 1951.

The committee consists of 106 members, of whom 89 are voting members; 32 are classified as consumers, 37 as producers, and 20 as general interest members.

The election of officers for the ensuing two years resulted in the selection of the following:

Chairman, K. G. Compton.
Vice-Chairman, W. H. Finkeldey.
Secretary, A. W. Tracy.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the three test methods under its jurisdiction be continued as tentative pending further study:

Tentative Methods of Tests for:

Total Immersion Corrosion Testing of Non-Ferrous Metals (B 185 - 43 T),
Salt Spray Fog Testing (B 117 - 49 T), and
Alternate Immersion Corrosion Test of Non-Ferrous Metals (B 192 - 44 T).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Total Immersion Test (A. W. Tracy, chairman).—Samples of metal and test directions are being sent to several committee members who have volunteered to cooperate in making tests under the Tentative Method of Total Immersion Testing of Non-Ferrous Metals (B 185 - 43 T).

Subcommittee III on Spray Test (C. O. Durbin, chairman).—A subgroup has been active during the year in studying an acetic acid-salt spray test for testing plated coatings on zinc-base die castings.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman).—All of the test specimens remaining at the various test sites were removed during the year. The 9 by 12-in. plate specimens were inspected by a task group at the Bell Telephone Laboratories on January 29. Weight loss determinations will be made on the plate specimens in accordance with the procedure followed in the past. Tension test specimens will be distributed to the cooperating laboratories for testing. It is the present plan of the subcommittee to complete the foregoing testing work within the next three or four months and to prepare a final report for presentation in 1953.

Subcommittee VII on Weather (F. L. LaQue, chairman).—The principal activities have been the continuation of exposure tests of zinc and steel to calibrate the corrosivity of the atmospheres at several ASTM test sites. This is being undertaken by C. P. Larrabee and O. B. Ellis, who presented some preliminary results at a meeting of the subcommittee held at Atlantic City on June 21, 1951.

Mr. L. G. von Lossberg has continued his exploration of instruments that might be employed to measure pollution and other factors in atmospheric corrosion.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

This report has been submitted to letter ballot of the committee, which consists of 88 voting members; 55 returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

K. G. COMPTON,
Chairman.

A. W. TRACY,
Secretary.

REPORT OF COMMITTEE B-4

ON

ELECTRICAL HEATING, RESISTANCE, AND RELATED ALLOYS*

Committee B-4 on Electrical Heating, Resistance, and Related Alloys has held three meetings since the presentation of its previous report as follows: In Atlantic City, June 18 and 19, 1951; in Philadelphia, November 1 and 2, 1951; in Philadelphia, January 31 and February 1, 1952.

The present membership of Committee B-4 totals 64 members of whom 21 are producers, 34 are consumers, and 9 are general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee B-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

17 Per Cent Chromium-Iron Alloy for Sealing to Glass (B 256 – 51 T), and

28 Per Cent Chromium-Iron Alloy for Sealing to Glass (B 257 – 51 T).

Revision and Reversion to Tentative of Standard Method of:

Testing Thermostatic Metals (B 106 – 40), and

Test for Modulus of Elasticity of Thermostat Metals (B 223 – 50).

The Tentative Specifications B 256 – 51 T and B 257 – 51 T were accepted by the Standards Committee on July 10, 1951; the remaining recommendations were accepted on August 21, 1951. They all appear in the 1951 Supplement to Book of ASTM Standards, Part 2.

On February 15, 1952, the Administrative Committee on Standards accepted the following recommendations submitted by Committee B-4:

Revision of Tentative Methods of:

Testing Sleeves and Tubing for Radio Tube Cathodes (B 128 – 48 T).

Tentative Revision of Standard Method of:

Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 39).

NEW TENTATIVES

The committee recommends for publication as tentative the following proposed specifications and methods of test as appended hereto:[1]

Tentative Method of Test for:

Relative Thermionic Emissive Properties of Materials Used in Electron Tubes, and

Sag of Tungsten Wire.

Tentative Specifications for:

High-Resistivity, Low-Temperature Coefficient Wire, and

Round Chromium-Copper Wire for Electronic Devices.

PUBLISHED AS INFORMATION

Committee B-3 recommends that the Proposed Methods for Chemical Analysis of Electronic Nickel be published as information, as appended hereto.[2]

REVISION OF TENTATIVES

The committee recommends that the Tentative Methods of Testing Sleeves and Tubing for Radio Tube Cathodes (B 128 – 48 T) be revised as indicated in Appendix I.

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* Pesented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 2.

[2] See p. 160.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee is submitting revisions in three standards. The standards affected, together with the recommended revisions, are given in detail in Appendix I.

The recommendations appearing in this report have been submitted to letter ballot of the committee the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Electrical Heating Materials (C. L. Raynor, chairman) has made progress on the study of the effect of humidity on the life test and revisions involving humidity and emissivity will be incorporated in the Method of Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 39). The proposed tentative specification for high-resistivity, low-temperature coefficient wires appended to this report was developed in response to stated needs in the manufacture of the Army-Navy resistors according to their specification JAN-R-93.

Subcommittee V on Wrought and Cast Alloys for High Temperature Use (E. Edmunds, chairman) has Tentative Specification B 207 – 46 T under consideration for revision in tensile strength ratings. Also the oxidation test method for thermal fatigue methods is being reviewed.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman) has continued to work on width-thickness ratios and has also considered the relation of tube flexivity. Work is near completion in the coordination of the methods considered.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (S. A. Standing, chairman) has continued actively the work on specifications for electronic tubes and lamps. This group comprises several very active sections on cathode nickel, fine wires, and micas.

Section A on Nickel-Cathode Materials has continued to study the performance of cathode melts leading to figures of merit. Noteworthy in its work are the observations concerned with a certain heat of metal (notably melt 82) and it has appeared to give inferior performance to the standard melt 66. Further analysis and observations brought forth evidence that such melts as 82 have somewhat lower cobalt content and inadequate service life on tube types which require a high figure of merit. This group has prepared a report representative of this kind of performance which has been brought to the attention of the JETEC Task Force on Critical Materials and the National Production Authority; the latter groups are concerned with the general supplies of nickel. In Section A a complete revision of the Tentative Methods of Testing Sleeves and Tubing for Radio Tube Cathodes (B 148 – 48 T) has been made to bring it up to date. Other work of this group has resulted in the development of chemical test methods for cathode nickel. These are chiefly concerned with the analysis for copper, nickel, cobalt, iron, manganese, and titanium. Spectrographic studies are being actively conducted in relation to cathode nickel, and specifications for the standard diode have been corrected and revised and are in the letter ballot stage.

Section C on Fine Wires has made progress in a study concerned with the weighing of fine wires on which it is intended to write a method of test or recommended practice. In addition, a proposed tentative specification has been written for chromium-copper wire as commonly used for grid supports. With this ground work, preparation of specifications for other common wire products used in the radio tube and lamp fields is under way.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Section F on Micas has reviewed Methods D 652 on mica stampings and the revision was presented to Committee D-9.

Subcommittee IX on Method of Test for Alloys in Controlled Atmospheres (P. H. Brace, chairman).—Prominent in the work of this subcommittee was the report entitled "Investigation of the Effect of Furnace Temperature on Molecular Completion of Test Gas by a Dynamic Sampling Procedure." Work continued on the mechanism of gas reactions in the ASTM controlled atmosphere furnaces.

Subcommittee X on Contact Materials (F. E. Carter, chairman) has continued its work on the "Surety of Making a Circuit" by various contact materials after oxidation and sulfidation treatment; the effects of surface finish and of type of testing device have been thoroughly examined; methods of measuring the thermal conductivity of contact materials have been investigated. Efforts to standardize forms and sizes of contacts have been continued. A new edition of the Bibliography and Abstracts on Electrical Contacts, bringing the references up to date, has been completed.[4]

This report has been submitted to letter ballot of the committee, which consists of 67 members; 64 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

S. A. STANDING,
Chairman.

STANTON UMBREIT,
Secretary.

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[4] Issued as ASTM *STP No. 56-G.*

Editorial Note

Subsequent to the Annual Meeting, Committee B-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Test for Determining Hardness of Contact Materials (B 277 - 52 T).

Tentative Recommended Practice for:

Sublimation Testing by the Electrical Resistance Method (B 278 - 52 T).

These recommendations were accepted by the Standards Committee on December 12, 1952. The new tentatives are available as separates and appear in the Compilation of ASTM Standards on Electrical Heating, Resistance, and Related Alloys.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRICAL HEATING, RESISTANCE, AND RELATED ALLOYS

In this Appendix are given the recommendations affecting certain standards covering electrical heating, resistance, and related alloys which are referred to earlier in this report. The standards appear in their present form in the 1949 Book of ASTM Standards, Part 2.

REVISION OF TENTATIVE

The committee recommends revisions in the following tentative: **Tentative Methods of Testing Sleeves and Tubing for Radio Tube Cathodes (B 128 – 48 T):**

Section 6.—Revise to read as follows:

6. Wall thickness shall be measured by a barrel micrometer reading direct to 0.0001 in. which meets one of the following two requirements:

(*1*) The spindle shall have a conical face with a flat of 0.020 ± 0.002 in. in diameter, or

(*2*) The spindle and anvil shall have conical faces with flats of 0.020 ± 0.002 in. in diameter.

Section 7.—Revise to read as follows:

7. In determining wall thickness of round or shaped sleeves or tubing, the test specimen shall be slit open longitudinally with a sharp instrument. The inside radius of the slit portion shall be enlarged by slight pressure to permit entrance of the micrometer spindle. Care shall be taken that burrs shall not interfere. When using the barrel micrometer, the closed setting of the micrometer jaws shall be read without the specimen in place to obtain a true "zero" reading. The micrometer shall then be read with the specimen inserted. Wall thickness shall be reported as the difference between these two readings. Pressures used for the zero setting and for the measurements on the specimen shall be as uniform as possible and sufficiently low as to avoid indenting the specimen.

Figure 1.—Delete present Fig. 1 and replace with accompanying Fig. 1.

New Section.—Add new Sections 11 and 12 on INTEGRAL TAB STRENGTH immediately following section on LENGTH and renumber subsequent section numbers accordingly.

INTEGRAL TAB STRENGTH

Apparatus

11. *Integral Tab Strength Tester.*—An integral tab strength tester as shown in Fig. 2.

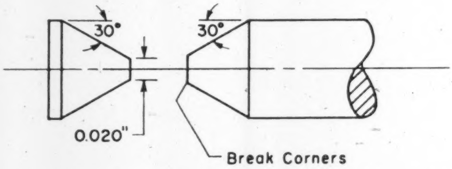

FIG. 1.—Conical Piont Spindle and Anvil for Barrel Micrometer.

Procedure

12. Open jaw to allow end of cathode to rest on indexing fixture. Close jaw on cathode. Attach 2-oz weight by clamp on to tab up to indexing gage. Exercise extreme care to avoid dropping weight when releasing it from fingers (plane of tab must not be twisted). Slide indexing gage away to the right side. Starting with sleeve, tab and weight in vertical position, rotate the pivot handle with uniform motion against the horizontal stops. Each contact with the stop counts as one bend. Speed of rotation must be slow enough to avoid pendulum

movement of weight and is not to exceed 1 turn per second. Continue bending until tab fractures and weight falls to base pad. Report number of bends prior to fracture.

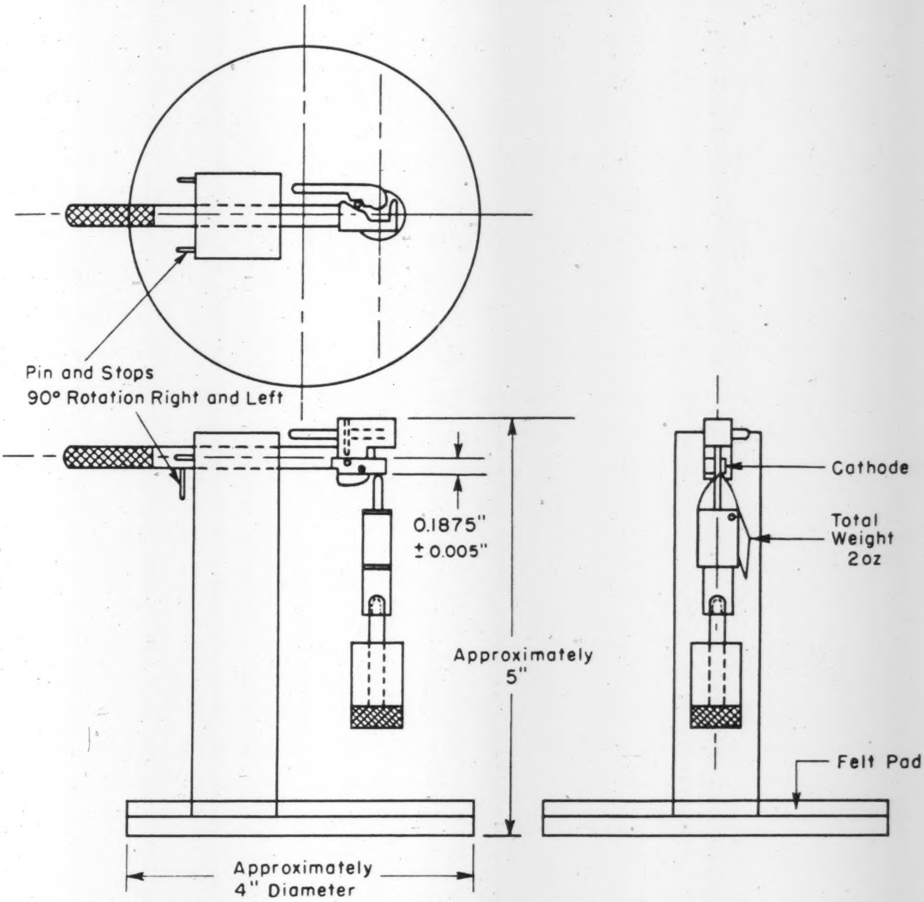

FIG. 2.—Apparatus Assembly for Measuring Location of Beads.

NOTE.—This is a referee test in case of questionable quality. It is intended to be a production control or customer acceptance test.

Figure 2.—Replace the present Fig. 2 with the accompanying Fig. 2.

Section 11.—Delete Paragraphs (*c*) and (*d*).

Section 12.—Revise Paragraphs (*b*) and (*c*) to read as follows:

(*b*) *Width and Location of circumferential Beads.*—The width and location of a circumferential bead shall be measured by an optical measuring instrument of at least 20× magnification. The reference points shall be determined by the centers of the radii at which the bead emerges from the longitudinal surface of the sleeve.

(*c*) *Location of longitudinal Beads.*—Vertical embossed cathodes are to be checked with "go and no-go" hole gages as described in Appendix I. The location longitudinally is to be checked as in Section 12(*b*).

Section 13.—Revise to read as follows:

13. An optical projector with measuring attachment is required, with at least two different magnifications, 10× and 20×, and a screen with

a reference line. Also required is a suitable jig for holding the cathode without distorting it and for rotating it about its longitudinal axis. Such a jig might, in simple form, consist of a gage pin supported in a vertical position by a drill chuck which can be rotated. The gage pin should be one or two thousandths of an inch smaller in diameter than the minimum cathode I.D. to be inspected so that the cathode will fall freely on the gage pin.

Section 14.—Revise to read as follows:

14. The magnification of the projector shall be set so that the entire length of the cathode appears on the screen. For the usual 14 in. diameter screen, this means that 20× is suitable for cathodes up to 17.5 mm long, 10× is suitable for cathodes up to 35 mm, and 5× (not usually available) is required for cathodes from 35 to 70 mm long.

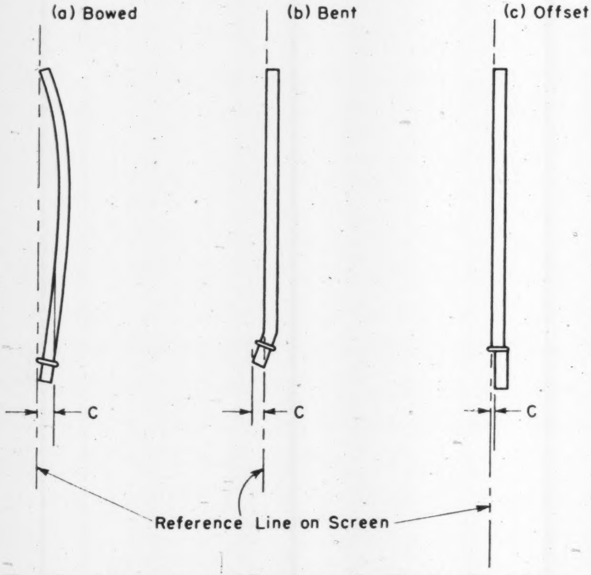

FIG. 3.—Arrangement of Specimens for Testing Straightness.

A gage pin of suitable size is then placed in the jig, the cathode dropped over it, and the jig rotated to ascertain the maximum deviation from straightness of the cathode. This deviation is then measured. The types of deviation are as shown in Fig. 3 and are measured as follows:

(*a*) *Bowed.*—As written.

(*b*) *Bent.*—As written.

(*c*) *Offset.*—As written.

Figure 3.—Replace present Fig. 3 with accompanying Fig. 3.

Section 15(b).—Delete Paragraph (*2*).

Figures 7 and 8.—Delete and renumber subsequent figures accordingly.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Committee B-4 recommends for immediate adoption revision of the following three standards and accordingly requests the necessary nine-tenths vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical-Heating Elements (B 82 – 46).

Section 10.—Change round wire tolerance to read as follows:

0.005 in. diameter and larger........	± 5 per cent
Finer than 0.005 in. to 0.002 in. diameter incl........................	± 8 per cent
Finer than 0.002 in. diameter.......	±10 per cent

Standard Specifications for Drawn or Rolled Alloy, 60 per cent Nickel, 16 per cent Chromium, and Balance Iron, for Electrical-Heating Elements (B 83 – 46):

Section 10.—Change round wire tolerance to read as follows:

0.005 in. diameter and larger.......	±5 per cent
Finer than 0.005 in. to 0.002 in. diameter incl......................	± 8 per cent
Finer than 0.002 in. diameter	±10 per cent

Standard Method of Test for Temperature-Resistance Constants of Alloy Wires for Precision Resistors (B 84 – 45):

Scope.—Delete "note" and last sentence and add the following:

Part I covers alloys of the manganin type having an approximate composition of 84 per cent copper, 12 per cent manganese and 4 per cent nickel; and the constantan type having a composition of about 55 per cent copper and 45 per cent nickel. It is applicable to materials normally used in the temperature range of from 0 C to 80 C.

Part II covers alloys with a high specific resistance and a low change in resistance with temperature between approximately −60 C and 250 C.

Delete the Note.

Part I.—Before "SAMPLING" insert "PART I" and keep the balance of Method B 84 – 45 unchanged as PART I.

Part II.—After the present Section 14, add the following as PART II:

PART II

Sampling

15. To read the same as Section 2.

Test Specimen

16. To read the same as Section 3.

Terminals

17. To read the same as Section 4.

Preliminary Treatment of Specimen

18. To read the same as Section 5.

Apparatus

19. To read the same as Section 6.

Chambers

20. (*a*) Baths for use from −60 C to +15 C shall consist of toluol. A refrigerated chamber may also be used.

(*b*) Baths for use above +15 C to +250 C shall consist of chemically neutral oils with a low viscosity and a flash point at least 50 C higher than the temperature of use.

(*c*) The liquid in these baths shall be of such quantity and so well stirred that the temperature in the region occupied by the specimen and the thermometer will be uniform within 0.5 C for any temperature between −60 C and +100 C and 1.0 C for any temperature above 100 C to 250 C.

(*d*) An acetone bath at room temperature shall be used to rinse samples free of oil before going into the toluol bath.

Temperature Measurements

21. The temperature shall be measured with a laboratory type thermometer or a resistance thermometer to an accuracy of ±0.5 C.

Resistance Measurements

22. To read the same as Section 9.

Procedure

23. (*a*) To read the same as Section 10(*a*).

(*b*) To read the same as Section 10(*b*).

(*c*) In this manner a series of determinations of the change of resistance with temperature shall be made for the desired descending temperature range, measurements being taken at approximately 25 C intervals.

(*d*) To read the same as Section 10(*d*).

(*e*) To read the same as Section 10(*e*).

Report

24. The report shall include the following.

(*a*) Identification of specimen.

(*b*) Description of material and its insulation.

(*c*) Length of wire in specimen and approximate resistance.

(*d*) Tabular list of resistance and temperatures in the order taken.

(*e*) Temperature of measuring apparatus and room at start and finish of test.

(*f*) Value of temperature coefficient in ohms per ohm per degree centigrade. This value shall be calculated using the following formula:

$$\frac{R_2 - R_1}{R_1(T_2 - T_1)} = \text{Temperature coefficient of resistivity.}$$

where:

R_1 = Resistance of specimen at the lower temperature in ohms.

R_2 = Resistance of specimen at the higher temperature in ohms.

T_1 = Temperature of the bath at the lower temperature in degrees centigrade.

T_2 = Temperature of the bath at the higher temperature in degrees centigrade.

APPENDIX II

PROPOSED METHODS FOR CHEMICAL ANALYSIS OF ELECTRONIC NICKEL[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.

Scope

1. (*a*) These methods cover procedures for the chemical analysis[2] of electronic nickel having chemical compositions within the following limits:

Cobalt, per cent	0.01 to 1.0
Copper, per cent	0.01 to 1.0
Iron, per cent	0.01 to 1.0
Titanium, per cent	0.001 to 0.1
Manganese, per cent	0.01 to 1.5

(*b*) The analytical procedures appear in the following order:

	Sections
Cobalt by the Nitroso-R-Salt (Photometric) Method	3 to 9
Copper by the Hydrobromic Acid (Photometric) Method	10 to 17
Manganese by the Periodate (Photometric) Method	18 to 24
Iron and Titanium by the Tiron (Photometric) Method	25 to 32

Treatment of Sample

2. Dissolve 1 g of the sample in 10 ml of HNO_3 (1:1) in a covered beaker by heating gently. When dissolution is complete, boil to expel brown fumes, cool, transfer to a 100-ml volumetric flask, and dilute to the mark. Use aliquots of this solution for determining cobalt, iron, titanium, and manganese.

COBALT BY THE NITROSO-R-SALT (PHOTOMETRIC) METHOD

Principle of Method

3. Cobalt in a hot solution buffered with sodium acetate forms on orange-colored complex with nitroso-R-salt. The addition of a controlled amount of HNO_3 destroys interfering complexes and stabilizes the cobalt complex. Photometric measurement is made at approximately 520 $m\mu$.

Concentration Range

4. The recommended concentration range is from 0.005 to 0.10 mg of cobalt in 50 ml of solution, using a cell depth of 2 cm, or 0.005 to 0.20 mg, using a cell depth of 1 cm.

Stability of Color

5. The color is stable for more than 2 hr.

Interfering Elements

6. The elements ordinarily present in electronic nickel do not interfere if their contents are under the maximum limits shown in Section 1.

Reagents

7. (*a*) *Standard Cobalt Solution* (*1 ml = 0.01 mg Co*):

(*1*) Transfer 0.1000 g of cobalt to a 1-liter volumetric flask. Add 10 ml of HNO_3 (1:1), heat gently until action ceases, and then boil until free of brown fumes. Cool, dilute to the mark, and mix. Transfer 100 ml of this solution to a 1-liter volumetric flask, dilute to the mark, and mix.

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[1] Published as information, June, 1952.

[2] For additional information on apparatus and reagents and on photometric practice, reference may be made to the Recommended Practices for Apparatus and Reagents for Chemical Analysis of Metals (ASTM Designation: E 50) and the Tentative Recommended Practice for Photometric Methods for Chemical Analysis of Metals (ASTM Designation: E 60), 1950 Book of ASTM Methods for Chemical Analysis of Metals.

(2) Alternatively, transfer 0.4770 g of $CoSO_4 \cdot 7H_2O$ to a 1-liter volumetric flask. Add 75 ml of water and 4 ml of H_2SO_4 (1:1). Swirl until the salt dissolves, dilute to the mark, and mix. Standardize the solution as follows: Transfer a 100-ml aliquot to a 400-ml beaker, add 10 ml of HCl (sp gr 1.18) and dilute to 200 ml. Proceed as described in Section 11 (*c*), (*f*), and (*h*) of the Standard Methods for Chemical Analysis of Nickel (ASTM Designation: E 39 – 45).[3] For use, dilute 100 ml of this solution to 1 liter in a volumetric flask and mix.

(*b*) *Sodium Acetate Solution* (*300 g per l*).—Dissolve 500 g of sodium acetate trihydrate in about 600 ml of water, filter, and dilute to 1 liter.

(*c*) *Nitroso-R-Salt Solution* (*7.5 g per l*).—Dissolve 0.75 g of nitroso-R-salt in water, filter, and dilute to 100 ml. Do not use solutions more than 1 week old.

Preparation of Calibration Curve

8. (*a*) *Calibration Solutions*.—Transfer 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, and 10.0 ml of cobalt solution (1 ml = 0.01 mg Co) to seven 50-ml beakers and dilute to 10 ml. Proceed in accordance with Paragraph (*c*).

(*b*) *Reference Solution*.—Transfer 10 ml of water to a 50-ml beaker and proceed in accordance with Paragraph (*c*).

(*c*) *Color Development*.—Add 5 ml of sodium acetate solution followed by 2.0 ml of nitroso-R-salt solution, swirling the solution after each addition. (The pH of the solutions at this point should be about 5.5.) Cover the beaker, heat to boiling, and maintain just under the boiling temperature for 1 to 2 min. Add 5.0 ml of HNO_3 (1:2) and boil gently for 1 to 2 min. Cool to room temperature. Transfer to a 50-ml volumetric flask, dilute to the mark, and mix.

(*d*) *Photometry*.—Transfer a suitable portion of the reference solution to an absorption cell and adjust the photometer to the initial setting, using a light band centered at approximately 520 mμ. While maintaining this photometer adjustment, take the photometric readings of the calibration solution.

(*e*) *Calibration Curve*.—Plot the photometric readings of the calibration solutions against milligrams of cobalt per 50 ml of solution.

Procedure

9. (*a*) *Sample Solution*.—Transfer 10 ml of the solution of the sample (Section 2) to a 100-ml volumetric flask, dilute to the mark, and mix. Transfer 5 ml of this solution to a 50-ml beaker and proceed as described in Section 8 (*c*).

(*b*) *Reference Solution*.—Transfer 10 ml of water to a 50-ml beaker and proceed as described in Section 8 (*c*).

(*c*) *Photometry*.—Take the photometric reading of the sample solution as directed in Section 8 (*d*).

(*d*) *Reagent Blank*.—Make a blank determination, following the same procedure and using the same amounts of all reagents.

(*e*) *Background Color*.—Transfer a 5-ml aliquot of the solution of the sample (Section 2) to a 50-ml beaker and proceed as described in Section 8 (*c*), but omit the addition of nitroso-R-salt. Take the photometric reading of this solution, using a 5-ml aliquot of the reagent blank solution, similarly treated, as the reference solution.

(*f*) *Calculation*.—Convert the photometric readings of the sample, reagent blank, and background color solutions to milligrams of cobalt by means of the calibration curve. Calculate the percentage of cobalt as follows:

$$\text{Cobalt, per cent} = \frac{A - B - C}{D \times 10}$$

where:

A = milligrams of cobalt found in the aliquot used,

B = reagent blank correction, in milligrams of cobalt,

C = background color correction, in milligrams of cobalt,

D = grams of sample represented in the aliquot used.

COPPER BY THE HYDROBROMIC ACID (PHOTOMETRIC) METHOD

Scope

10. This method covers the determination of copper in amounts under 1 per cent;

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[3] 1950 Book of ASTM Methods for Chemical Analysis of Metals.

higher concentrations are best determined by the electrolytic method.

Principle of Method

11. Cupric copper in a mixture of hydrobromic and phosphoric acids forms a red-violet-colored complex. Photometric measurement is made at approximately 600 mμ.

Concentration Range

12. The recommended concentration range is from 0.05 to 0.6 mg of copper in 25 ml of solution.

Stability of Color

13. The color develops immediately and is stable for at least 2 hr.

Interfering Elements

14. Provision has been made in the method to eliminate interfering elements ordinarily found in electronic nickel. Precious metals other than silver will cause interference.

Reagents

15. (*a*) *Standard Copper Solution (1 ml = 0.1 mg Cu)*.—Dissolve 0.1000 g of copper (99.9 per cent Cu) in 30 ml of HCl (1:1) and 5 ml of H_2O_2 (30 per cent). When solution is complete, boil gently until the H_2O_2 is decomposed and the chlorine removed. Cool, dilute to 1 liter in a volumetric flask, and mix.

(*b*) *Test Lead (copper-free)*.—Finely granulated lead passing 51-gage nylon cloth.

(*c*) *Hydrobromic Acid – Bromine Mixture.*—Dilute 1 volume of bromine with 19 volumes of HBr (48 per cent).

Preparation of Calibration Curve

16. (*a*) Transfer 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 ml of standard copper solution (1 ml = 0.1 mg Cu) to seven 100-ml beakers, add 1 ml of HCl (sp gr 1.18), dilute to 40 ml, and proceed in accordance with Paragraphs (*b*) to (*d*).

(*b*) Place 1.0 g of finely granulated lead in each beaker and heat to boiling; continue boiling for 10 to 15 min to displace the copper. Cool and discard the solution, including one water wash by decantation. Transfer the beaker to a hot plate to remove moisture. Dissolve the metal in the beaker in 10 ml of the HBr - Br_2 mixture, applying a little heat if necessary. Then increase the temperature to boil off bromine (until no more bromine is discernable in the upper part of the beaker). Cool and add 2 drops of the HBr - Br_2 mixture and transfer to a 25-ml volumetric flask. Add 10 ml of H_3PO_4 (85 per cent). Rinse the beaker with small increments of HBr (48 per cent) using this to fill the flask to the mark. Stopper the flask and shake until the precipitate that forms is completely dissolved.

(*c*) Transfer suitable portions to dry absorption cells and measure the transmittancy of the solutions at approximately 600 mμ, using the blank of reagents in the reference cell.

(*d*) Plot the values obtained against milligrams of copper per 25 ml of solution.

Procedure

17. (*a*) Transfer 0.500 g of the sample, containing up to 0.6 mg of copper, to a 250-ml beaker. Cover with a watch glass, add 10 to 12 ml of HCl (sp gr 1.18), and heat gently to dissolve. Add a few drops of H_2O_2 (30 per cent), and boil gently until the H_2O_2 oxidant is decomposed and the chlorine removed. Continue the evaporation to the point where the acid concentration will be the same when diluted to 40 ml as it was in preparation of the calibration curve. Then continue in accordance with Section 16 (*b*) and (*c*).

(*b*) *Calculation.*—Convert the photometric readings of the sample to milligrams of copper by means of the calibration curve, and calculate the percentage of copper as follows:

$$\text{Copper, per cent} = \frac{A}{B \times 10}$$

where:

A = milligrams of copper found, and
B = grams of sample used.

MANGANESE BY THE PERIODATE (PHOTOMETRIC) METHOD

Principle of Method

18. Manganese in acid solution is oxidized to permanganate by means of KIO_4.

Photometric measurement is made at approximately 515 mμ.

Concentration Range

19. The recommended concentration range is 0.05 to 1.5 mg of manganese per 100 ml of solution.

Stability of Color

20. The color is permanent in the absence of reducing agents.

Interfering Elements

21. Reducing substances reacting with periodate or permanganate must be removed or destroyed before the periodate oxidation is attempted. Foreign metals, with a few exceptions, do not interfere, except when they are colored. The effect of copper, cobalt, etc., is compensated for by the use of an aliquot portion of the sample solution in the reference cell.

Reagents

22. (*a*) *Standard Manganese Solution* (*1 ml = 0.1 mg Mn*).—Dissolve 0.1000 g of pure manganese metal in 10 ml of HNO_3 (1:1) in a covered 100-ml beaker by gentle heat. Boil to expel the brown fumes, cool, and dilute to 1 liter in a volumetric flask.

(*b*) *Potassium Periodate Solution* (*10 g* KIO_4 *per liter*).—Dissolve 10 g of KIO_4 in water, add 5 ml of HNO_3 (sp gr 1.42), and dilute to 1 liter.

(*c*) *Sodium Nitrite Solution* (*20 g* $NaNO_2$ *per liter*).—Dissolve 0.2 g of $NaNO_2$ in water and dilute to 10 ml. Do not use solutions more than 1 day old.

Preparation of Calibration Curve

23. (*a*) Transfer 0.0, 1.0, 3.0, 5.0, 10.0, and 14.0 ml of the standard manganese solution to 125-ml Erlenmeyer flasks. Dilute to 20 ml. Add 10 ml of HNO_3 (sp gr 1.42), 2.5 ml of H_3PO_4 (85 per cent), and 10 ml of KIO_4 solution. Heat to boiling and boil gently for 2 min; then digest just below boiling for 10 min to develop full intensity of color. Cool, transfer to a 100-ml volumetric flask, dilute to the mark, and mix.

(*b*) *Photometry.*—Using the reagent blank for the reference solution, obtain transmittancy of the calibration solution at approximately 515 mμ.

(*c*) *Calibration Curve.*—Plot the photometric readings of the calibration solutions against milligrams of manganese per 100 ml of solution.

Procedure

24. (*a*) *Sample Solution.*—Transfer 10 ml of the solution of the sample (Section 2) to a 125-ml Erlenmeyer flask and dilute to 20 ml. Add 10 ml of HNO_3 (sp gr 1.42), 2.5 ml of H_3PO_4 (85 per cent), and 10 ml of KIO_4 solution, and determine the manganese as in the preparation of the calibration curve, using as the reference solution either:

(*1*) a 10-ml portion of the solution of the sample (Section 2) that has been decolorized by addition of one drop of $NaNO_2$ solution, or

(*2*) a solution prepared by treating an aliquot of the solution of the sample in the same manner as the test solution, except to omit the addition of KIO_4.

(*b*) *Calculation.*—Calculate the percentage of manganese as follows:

Manganese, per cent = mg Mn in 10 ml of the sample solution

IRON AND TITANIUM BY THE TIRON (PHOTOMETRIC) METHOD

Scope

25. This method covers a photometric procedure for the simultaneous determination of iron and titanium in electronic nickel.

Principle of Method

26. After preliminary separation, the absorption of the Tiron complex of iron is measured at 560 mμ, the color of the iron is bleached with sodium dithionite, and the titanium is measured at 399 mμ.

Concentration Range

27. The recommended concentration range is 0.01 to 0.1 mg for iron and 0.01 to 0.08 mg for titanium.

Stability of Color

28. Literature states that the color should be stable for 24 hr, but since sodium

dithionite is unstable and decomposes at low pH values precipitating colloidal sulfur, the readings should be taken within 20 min when sodium dithionite is used.

Interfering Elements

29. Separation of the iron and titanium prevents any interference from diverse ions.

Reagents

30. (*a*) *Tiron Solution.*—Dissolve 4 g of disodium-1, 2-dihydroxybenzene-3, 5-disulfonate in 100 ml of water. The water-clear solution becomes pale yellow on standing several weeks and should be discarded.

(*b*) *Buffer Solution.*—Mix equal volumes of 1 *M* sodium acetate solution and 1 *M* acetic acid. The pH of the solution is 4.7.

(*c*) *Sodium Dithionite.*—Sodium hydrosulfite ($Na_2S_2O_4$).

(*d*) *Standard Iron Solution (1 ml = 0.1 mg Fe).*—Dissolve 0.8635 g of ferric ammonium sulfate ($FeNH_4(SO_4)_2 \cdot 12H_2O$) in 10 ml of H_2SO_4 (1:9) and dilute to 1 liter.

(*e*) *Standard Titanium Solution (1 ml = 0.1 mg Ti).*—Fuse 0.1668 g of TiO_2 with 2 g of $KHSO_4$ in a platinum crucible. Make up to 1 liter with water.

Preparation of Calibration Curves

31. (*a*) Transfer 1.0, 2.0, 4.0, 6.0, 8.0, and 10.0 ml of the standard iron solution to 50-ml beakers, add 5 ml of Tiron solution, and adjust the pH to 4.7 ± 0.1 with NH_4OH. (This must be done very accurately.) Transfer the solution to a 50-ml volumetric flask, and wash the beaker with 5 ml of buffer solution and enough water to bring the solution to the mark. Mix, and measure the transmittancy at 560 mμ, using a blank of the same quantities of reagents in the reference cell. Plot the values obtained against milligrams of iron per 50 ml of solution.

(*b*) Transfer 1.0, 2.0, 4.0, 6.0, and 8.0 ml of standard titanium solution to 50-ml beakers, add 5 ml of Tiron solution, and adjust the pH to 4.7 ± 0.1 with NH_4OH. Transfer the solution to a 50-ml volumetric flask, and wash the beaker with 5 ml of buffer solution and enough water to bring the solution to the mark. Add about 20 to 25 mg of sodium dithionite, mix carefully, and measure the transmittancy at 399 mμ, using a blank of the same quantities of reagents in the reference cell. Plot the values obtained against milligrams of titanium per 50 ml of solution.

Procedure

32. (*a*) Transfer 10 ml of the solution of the sample (Section 2) to a 50-ml beaker, warm gently and make ammoniacal to precipitate iron and titanium. Allow the solution to stand for about an hour or until the precipitate coagulates. Filter and wash with water made ammoniacal, making sure that all blue coloration is removed from the filter paper.

(*b*) Dissolve the precipitate into the original beaker (Note) with H_2SO_4 (1:5), keeping the volume to a maximum of about 10 ml. Add 5 ml of Tiron solution and adjust the pH to 4.7 ± 0.1 with NH_4OH. Transfer to a 50-ml volumetric flask, wash the beaker with 5 ml of buffer solution and enough water to bring the solution to the mark, and mix.

NOTE.—Instead of dissolving the precipitate into the original beaker, the filter paper containing the iron and titanium may be transferred to the original beaker and the filter paper decomposed with HNO_3 and a small amount of H_2SO_4. Then dilute to about 10 ml with water and proceed with the addition of Tiron solution.

(*c*) Measure the transmittancy at 560 mμ. Then bleach the color of the iron complex by adding a very few crystals of sodium dithionite to the solution in the cell, and with as little agitation as possible but sufficient to effect complete mixing. Measure the transmittancy of the titanium complex at 399 mμ. If the amounts of iron and titanium differ in order of magnitude, it will be necessary to use separate aliquots of suitable size for the determination of each metal.

(*d*) *Calculations.*—Calculate the percentages of iron and titanium as follows:

Iron, per cent = mg Fe found in 10 ml of the sample solution

Titanium, per cent = mg Ti found in 10 ml of the sample solution

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT*

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held two meetings during the year: at Washington, D. C. on October 4, 1951, and at New York, N. Y. on January 31, 1952. At these sessions Subcommittees W-1, W-2, W-3, W-4, and F-1 also met; the Advisory Committee met at New York on November 9, 1951 and January 30, 1952; Subcommittee G-1 met at Washington on October 3, 1951, and Subcommittee G-3 at New York, January 30, 1952.

During the year 7 members were added to the committee and there were 11 removals. At the present time the committee consists of 136 members, of whom 114 are voting members; 53 are classified as producers, 41 as consumers, and 20 as general interest members.

At the meeting on January 31, 1952, the election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, G. H. Harnden.
First Vice-Chairman, H. C. Ashley.
Second Vice-Chairman, J. J. Kanter.
Secretary, V. P. Weaver

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting 2 new tentative specifications, revisions in 7 tentative specifications, revisions in 27 standards for immediate adoption, the adoption of 18 tentatives as standard, and the withdrawal of 1 tentative. The standards and tentatives affected, together with the revisions recommended, are covered in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF THE ADVISORY COMMITTEE

It was recommended that the Tentative Classification of Coppers, B 224, be adopted as standard. Also, the Advisory Committee sponsored the organization of a supervisory group to act for the American Standards Association in administering the secretariat for ISO/TC/26, a Technical Committee of the International Organization for Standardization.

ACTIVITIES OF SUBCOMMITTEES

The following is the report of the several subcommittees during the year. The actions on standards are given in detail in the Appendix.

Subcommittee W-1 on Plate, Sheet, and Strip (S. A. Rosecrans, chairman) recommended that revisions be incorporated in three tentative specifications: B 19 for Cartridge Brass, B 122 for Copper-Nickel-Zinc and Copper-Nickel Alloy, and B 248 for General Requirements. Revisions for immediate adoption were recommended in Standard Specifications B 100 and B 171. Specifications B 36, B 130, and B 169 were recommended for adoption as standard without revision. Specifications B 121, B 152, and B 194 were also recommended for adoption as standard, with minor revisions.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

A task group (H. C. Ashley, chairman) prepared requirements for disks made from hot-rolled material to be incorporated in Specification B 19. A task group (W. D. France, chairman) prepared revisions in requirements for workmanship in Specification B 248. A task group (J. E. McGraw, chairman) prepared requirements for thicker plates to be incorporated in Specification B 171.

Among the subjects being studied by the subcommittee are the preparation of yield strength data for material covered by Specification B 11 used by the ASME, the revision of copper limits for alloy No. 6 in Specification B 121, the preparation of requirements for other copper-nickel-zinc alloys containing 10 per cent and 12 per cent nickel to be added to Specification B 122, and the preparation of requirements for manganese brass for resistance welding.

Subcommittee W-2 on Rods, Bars, and Shapes (J. D. MacQueen, chairman) recommended that revisions be incorporated in Tentative Specifications B 133 for Copper and B 249 for General Requirements. Revisions for immediate adoption were recommended in the following seven standard specifications:

ASTM Designation	Material
B 12	Copper Rods for Locomotive Staybolts
B 16	Free-Cutting Brass
B 98	Copper-Silicon Alloy
B 124	Copper and Copper-Base Alloy Forging Rods
B 138	Manganese Bronze
B 140	Leaded Red Brass (Hardware Bronze)
B 187	Copper Bus Bar

The following five tentative specifications were also recommended for adoption as standard, with minor revisions:

ASTM Designation	Material
B 21	Naval Brass
B 139	Phosphor Bronze
B 150	Aluminum Bronze
B 151	Copper-Nickel-Zinc-Alloy
B 196	Beryllium-Copper Alloy

A task group (B. J. Sirois, chairman) prepared revisions in hardness testing of rods and bars in Specifications B 133 and B 187. A task group (V. P. Weaver, chairman) prepared revisions in hardness testing of rods and bars in Specification B 16. A task group (G. C. Mutch, chairman) prepared requirements for yield strength of hard temper bars of alloys A, C, and D to be incorporated in Specification B 98. A task group (S. A. Rosecrans, chairman) prepared revision of requirements for test specimens in Specifications B 12, B 16, B 21, B 98, B 133, B 138, B 139, B 140, B 150, B 151, B 187, and B 249.

Among the subjects being considered by the subcommittee are the preparation of yield strength data for material covered by Specification B 12 used by ASME, a review of tensile requirements in Specification B 133, provision for hot-forged material in Specification B 138, the addition of copper-nickel-zinc alloys containing 10 per cent and 12 per cent nickel to Specification B 151, and the preparation of a specification for forgings.

Subcommittee W-3 on Wire and Wire Rod (W. D. France, chairman) recommended that revisions be incorporated in Tentative Specification B 250 for General Requirements. Revisions for immediate adoption were recommended in Standard Specification B 134 for Brass Wire. Specifications B 159 and B 206 were recommended for adoption as standard without revision. With minor revisions, Specification B 197 was also recommended for adoption as standard. The subcommittee recommends a proposed new Tentative Specification for Rectangular Copper Wire for General Purposes, prepared by a task group (B. J. Sirois, chairman).

Among the subjects being considered in the subcommittee is the preference of alloy No. 6 over alloy No. 7 in Specification B 134.

Subcommittee W-4 on Pipe and Tube (R. S. Pratt, chairman) recommended that revisions be incorporated in Tentative Specification B 251 for General Requirements. Revisions for immediate adoption were recommended in Standard Specification B 111 for Condenser Tubes. Specifications B 75 and B 188 were recommended for adoption as standard without revision. With minor revision, Specification B 135 was also recommended for adoption as standard.

A task group (W. D. France, chairman) prepared the revisions of iron content for 70-30 copper-nickel alloy in Specification B 111.

Among the subjects under consideration in the subcommittee are the preparation of a specification for refrigeration service seamless copper tube, the review of temper requirements in Specification B 75 for Seamless Copper Tubes, and the review of Rockwell hardness requirements in tube specifications. For Specification B 111, the subcommittee is studying the revision of dimensional tolerances. Dimensional tolerances for rectangular, hexagonal, and octagonal tubes are also being studied. Yield strength data are being prepared for the following specifications used by ASME: B 13, B 42, B 43, B 75, and B 111.

Subcommittee F-1 on Castings, and Ingots for Remelting (G. H. Clamer, chairman, M. L. Steinbuch, secretary) recommended revisions for immediate adoption in 14 standard specifications: B 22, B 61, B 62, B 66, B 67, B 132, B 143 to B 149 inclusive, and B 198. The subcommittee prepared a proposed new Tentative Specification for Copper-Base Alloy Centrifugal Castings. The subcommittee recommended that Specification B 53 for Silicon Copper, and Classification B 119 for Cast Copper-Base Alloys be reaffirmed, and that Recommended Practice for Preparing Tension Test Specimens for Copper-Base Alloys for Sand Castings B 208 be continued as tentative.

A task group (H. S. Ream, chairman) prepared the new Tentative Specification for Copper-Base Alloy Centrifugal Castings.

Among the subjects under consideration in the subcommittee is the preparation of a specification for a group of copper-nickel-tin-zinc alloys and a new tentative recommended code of procedure for the inspection of copper-base alloy sand castings.

Subcommittee G-1 on Methods of Test (G. R. Gohn, chairman, J. P. Guerard, secretary) recommended withdrawal of Tentative Methods, B 220, since these methods of test are now incorporated in the Tentative Methods of Tension Testing of Metallic Materials (E 8 – 51 T).

The subcommittee has completed studies on the effect of speed of testing on tensile properties and finds that within the ability of commercially available testing equipment to accurately record load and strain, there is no significant effect due to speed of test on tensile strength, yield strength or per cent elongation of copper and copper alloys. A paper summarizing the studies has been prepared by the chairman of the task group, N. H. Murdza, and is appended to this report.

The subcommittee is preparing a method of test covering the measurement of dimensions, such as thickness, width, diameter and length, and is assembling data from its members to ascertain what methods and instruments are now being used by the mills and consumers in making such measurements.

The subcommittee is continuing its work on the analysis of previous studies on the determination of grain size.

Subcommittee G-2 on Tolerances (J. E. McGraw, chairman) in cooperation with Subcommittee W-1, prepared dimensional tolerances for thicker plates in Specification B 171.

For all wrought product specifications prepared by Committee B-5, the subcommittee is reviewing dimensional tolerances as to desired accuracy and significance. The subcommittee is also studying straightness tolerances for short-length tubes in Specification B 135.

Mr. McGraw continues to represent Committee B-5 at sessions of the CABRA Standards Committee and in coordinating CABRA dimensional tolerances with those of Committee B-5.

Subcommittee G-3 on Editorial and Publications (W. F. Roeser, chairman) is preparing a detailed alphabetical subject index to the contents of the special volume of ASTM Standards on Copper and Copper Alloys. The subcommittee is also making efforts to publicize the results of task group investigations made by Committee B-5.

This report has been submitted to letter ballot of the committee, which consists of 114 voting members; 89 returned their ballots, of whom 86 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

G. H. HARNDEN,
Chairman.

V. P. WEAVER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-5 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Copper Rod, Bar, and Shapes (B 133 – 52 T).

Tentative Revision of Standard Specifications for:

Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 52), and
Manganese Bronze Rod, Bar, and Shapes (B 138 – 52).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the revised tentative and tentative revisions appear in the 1952 Book of ASTM Standards, Part 2.

On October 23, 1952, the Administrative Committee on Standards accepted the recommendation of Committee B-5 that the Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 – 52 T) be revised. The revised specifications appear in the 1952 Book of ASTM Standards, Part 2.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering copper and copper alloys which are referred to earlier in this report. The standards appear in their present form in the 1949 Book of ASTM Standards, Part 2, or in the 1950 and 1951 Supplements to the Book of ASTM Standards, Part 2.

NEW TENTATIVES

The committee recommends the following two new specifications for publication as tentative:

Tentative Specifications for:

Rectangular Copper Wire for General Purposes;[1]

Copper-Base Alloy Centrifugal Castings.[1]

REVISIONS OF TENTATIVES

The committee recommends that the following seven tentative specifications be revised as indicated below and continued as tentative.

Tentative Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 - 51 T):

Section 3(b).—Add the following: "Except that bar and disks of thickness 0.250 in and greater may be finished by hot rolling and overhauling."

Section 8.—In Paragraph (*b*) revise to read: "Annealed, cold-rolled material . . . ." Add Paragraph (*c*) to read: "(*c*) The minimum grain size of as-hot-rolled material for cartridge case disks and cups shall be agreed upon between the manufacturer and the purchaser at the time of placing the order."

Section 11.—Letter as Paragraph "(a)" and add Paragraph (*b*) to read: "For as-hot-rolled material, tension tests shall be made and the results shall conform to the requirements prescribed in Table II."

Table II.—In the title revise to read: ". . . Annealed and As-Hot-Rolled Tempers" and add the following:

Thickness	Tensile Strength, min, psi	Elongation in 2 in. min, per cent
AS-HOT-ROLLED		
0.250 to 0.500 in. incl.	43 000	55
Over 0.500 in.	40 000	60

Table VII.—Revise editorially the third size group to read "over 3" and delete the next two lines.

Tentative Specification for Copper-Nickel-Zinc and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 - 51 T):

Table I.—For alloy Nos. 5, 6, and 7, add minimum copper contents of "65.0", "74.0", and "70.0" per cent, respectively. For alloy No. 5, revise maximum iron "0.6" to read "0.70" per cent.

Tentative Specification for Copper Rod, Bar, and Shapes (B 133 - 51 T):

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[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 2.

Section 6.—Delete "B" scale Rockwell hardness.

Section 12.—In Paragraph (*a*) revise in the second sentence to read: "... shall be as specified in the Tentative Methods of Tension Testing of Metallic Materials (ASTM Designation: E 8)."

Add a new Paragraph (*b*) to read as follows, re-lettering the present Paragraph (*b*) as (*c*): "(*b*) The Rockwell test shall be made on the original longitudinal surface of the test specimen. In the case of hexagonal and octagonal rods and square bars, the Rockwell indentations shall be approximately along the center line of any one of the surfaces. For rectangular bars, the indentations shall be at least ⅛ in. from the edges of the bar."

Tentative Specification for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar (B 248 – 51 T):

Section 9.—Add a third sentence to read as follows: "A superficial film of residual light lubricant is normally present and is permissible unless otherwise specified."

Tentative Specification for General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes B 249 – 51 T):

Section 1.—Add Note 1 to read: "NOTE 1.—Requirements for flat wire (defined as flat product up to and including 0.188 in. in thickness and up to 1¼ in. in width, with all surfaces rolled or drawn, without having been slit, sheared or sawed) including square, furnished in coils or straight lengths, or on spools, reels or bucks are covered by the following wire specifications:

Title of Product Specification	ASTM Designation
Copper-Nickel-Zinc Alloy Wire	B 206
Rectangular Copper Wire for General Purposes	B 272

Add Note 2 to read: "NOTE 2.—Requirements for rolled bar as defined in Section 2(*d*) of ASTM Specification B 248 are covered by the following specifications:

Title of Product Specification	ASTM Designation[a]
Brass Plate, Sheet, Strip, and Rolled Bar	B 36
Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes	B 97
Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar	B 103
Leaded Brass Plate, Sheet, Strip, and Rolled Bar	B 121
Copper-Nickel-Zinc and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar	B 122
Copper Sheet, Strip, Plate, and Rolled Bar	B 152
Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar	B 169
Beryllium-Copper Alloy Plate, Sheet, Strip, and Rolled Bar	B 194

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[a] These designations refer to the latest issue of the respective specification.

Section 5.—Replace reference to "B 220" by "E 8".

Tentative Specification for General Requirements for Wrought Copper-Alloy Wire (B 250 – 51 T):

Title.—After "Wrought" add "Copper and."

Section 1(*a*).—In the second sentence add "copper and" before "copper-alloy."

Add "Rectangular Copper Wire for General Purposes, B 272" to the list of product specifications.

Section 4.—In Paragraph (*a*) revise the lot size to read: "*Lot Size.*—5000 lb or fraction thereof, except that for ASTM Designation B 272 (copper) the lot size shall be 10,000 lb or fraction thereof."

In Paragraph (*c*), first sentence, revise to read "For the physical tests (including resistivity when required) a sample shall be taken . . . . ."

Section 5.—In the list of tests add the following:

Chemical Analysis	E 53, Standard Method for Chemical Analysis of Copper (Electrolytic Determination of Copper)
Rockwell Hardness	E 18, Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
Electrical Resistivity	B 193, Standard Method of Test for Resistivity of Electrical Conductor Materials.

Section 6.—In the list of properties add "Hardness" and "Resistivity" to form one group with "Chemical Composition."

Section 8.—In Paragraph (*c*) revise "Tables III and IV" to read "Tables III, IV, and V." Revise reference to "Table III" and "Table IV" to read "Table IV" and "Table V," and add reference to a new Table III to read: "*Table III.*—Thickness tolerances for rectangular and square copper wire applicable to ASTM Designation B 272."

In Paragraph (*d*) revise "Tables V and VI" to read "Tables VI and VII" and revise reference to "Table V" to read "*Table VI.*—Width tolerances for rectangular wire applicable to ASTM Designations B 134 and B 272 (copper)."

Revise Paragraph (*e*) to read as follows:

(*e*) **Length:** (*1*) Round, hexagonal and octagonal wire shall be furnished in coils or reels, consisting of a single length as agreed upon by the manufacturer and the purchaser.

(*2*) Flat wire when furnished in straight, specific or stock lengths shall meet the tolerances shown in Table VIII.

Table VIII.—Length tolerances for straight lengths (specific or stock) of rectangular and square wire (Applicable to ASTM Designations B 134, B 206 and B 272).

(*3*) Soft flat copper wire, unless otherwise specified, may, at the manufacturer's option, be furnished in rolls, bucks or reels. Hard temper flat copper wire, unless otherwise specified, shall be furnished in straight lengths. Stock lengths with short lengths included as prescribed in Table IX shall be furnished unless the order specifically states that stock or specific lengths are required.

Table IX.—Schedule of lengths (specific and stock) with ends, for rectangular and square wire furnished in straight lengths, (applicable to ASTM Designations B 134, B 206 and B 272).

New Section.—Add a new Section 9 to read as follows, renumbering subsequent sections accordingly:

9. *Straightness:* For rectangular and square wire, the deviation from straightness shall not exceed the limitations prescribed in Table X. To determine compliance with this tolerance, the lengths shall, in case of disagreement, be checked by the following method: Place the lengths on a level table so that the arc or departure from straightness is horizontal. Measure the depth of arc to the nearest $\frac{1}{32}$ in. using a steel scale and a straight edge.

Section 9.—Renumber as Section 10 and revise to read: "Rectangular and square wire (applicable to ASTM Designations B 134, B 206 and B 272) may be furnished . . . ."

Appendix.—Add the following standard weights to the appendix for the material covered by the new Tentative Specification B 272.

TABLE I.—THICKNESS TOLERANCES FOR RECTANGULAR AND SQUARE WIRE.
(Applicable to ASTM Designation B 272)

Thickness, in.	Thickness Tolerances, plus and minus,[a] in., for Widths Given in Inches	
	Up to ½, incl.	Over ½ to 1¼, incl.
Up to 0.013, incl.	0.001	0.001
Over 0.013 to 0.050, incl.	0.0013	0.0013
Over 0.050 to 0.090, incl.	0.0015	0.0015
Over 0.090 to 0.130, incl.	0.002	0.002
Over 0.130 to 0.188, incl.	0.0025	0.0025

[a] If tolerances are specified as all plus or all minus, double the values given.

Material		Density, lb per cu in.
copper	deoxidized and oxygen-free	0.323
	other classifications	0.321

Tolerance Tables.—Add a new Table III to read as shown in the accompanying Table I, renumbering subsequent tables accordingly.

Table VII.—Revise title to read: "Length Tolerances for Straight Lengths (Specific or Stock) of Rectangular and Square Wire" (applicable to ASTM Designation B 272).

Add new Tables IX and X to read as shown in the accompanying Tables II and III.

Tentative Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 - 51 T):

Section 4(d).—In the first sentence revise to read: "... tube furnished in coils, a length sufficient for all necessary tests shall be cut. . . . ."

Table II.—Add $\frac{1}{4}$ in. size Type K having a nominal wall thickness 0.035 in., wall thickness tolerance of 0.0035 in., and theoretical weight of 0.145 lb per ft.

TABLE II.—SCHEDULE OF LENGTHS (SPECIFIC AND STOCK) WITH ENDS FOR RECTANGULAR AND SQUARE WIRE FURNISHED IN STRAIGHT LENGTHS.

(Applicable to ASTM Designations B 134, B 206, and B 272)

Square Wire, (Side in in.)	Rectangular Wire Area[a], sq. in.	Nominal Length, ft	Shortest Permissible Length[b] (In Per Cent of Nominal Length)	Maximum Permissible Weight of Ends (In Per Cent of Lot Weight)
Up to 0.188, incl	Up to 0.250, incl	6 to 14, incl	75	20

[a] Width times thickness, disregarding any rounded corners or edges.

[b] Expressed to the nearest ½ ft.

TABLE III.—STRAIGHTNESS TOLERANCES FOR RECTANGULAR AND SQUARE WIRE.

(Applicable to ASTM Designations B 134, B 206, and B 272)

Applicable to any longitudinal surface or edge of material supplied in nominal flat straight lengths and to any longitudinal edge of material supplied in rolls or on bucks.

When furnished in straight lengths, in rolls, or on bucks....................	½ in. maximum curvature (depth of arc) in any 6-ft portion of the total length.
When furnished on reels or in stagger wound rolls...	No straightness tolerances established.

WITHDRAWAL OF TENTATIVE

Tentative Methods of Tension Testing of Copper and Copper-Alloy Rods, Bars, and Shapes (B 220 - 48 T):

The committee recommends that Tentative Methods B 220 be withdrawn since the requirements are now covered in Tentative Methods E 8 - 51 T.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following seven tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Brass Plate, Sheet, Strip, and Rolled Bar (B 36 - 51 T),
Seamless Copper Tube (B 75 - 51 T),
Gilding Metal Strip (B 130 - 51 T),
Phosphor Bronze Wire (B 159 - 51 T),
Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar (B 169 - 51 T),
Seamless Copper Bus Pipe and Tube (B 188 - 51 T),
Classification of Coppers (B 224 - 48 T).

The committee recommends that the following eleven tentatives be approved for reference to letter ballot of the Scioety for adoption as standard with revisions as indicated:

Tentative Specification for Naval Brass Rod, Bar, and Shapes (B 21 - 51 T):

Table II.—For soft shapes add a footnote to read: "Tensile requirements for drawn shapes shall be as agreed upon between the manufacturer and the purchaser at the time of order."

Section 6.—In the first sentence delete "... but in no case less than twice its diameter or distance between parallel surfaces . . .".

Section 7(a).—Revise in the second sentence to read: "... shall be as specified in the Tentative Methods of Tension Testing of Metallic Materials (ASTM Designation: E 8)."

Tentative Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar (B 121 - 51 T):

Table I.—Revise copper limits for alloy No. 4 to read "59.0 to 64.5."

Tentative Specification for Seamless Brass Tube (B 135 - 51 T):

Table I.—For alloy No. 5, revise lead limit to read "0.30 max."

Tentative Specification for Phosphor Bronze Rod, Bar, and Shapes (B 139 - 51 T):

Section 6.—Revise as indicated above for Section 7(*a*) in Specification B 21.

Tentative Specification for Aluminum Bronze Rod, Bar, and Shapes (B 150 - 51 T):

Sections 6 and 7(a).—Revise as indicated above for Sections 6 and 7(*a*) in Specification B 21.

Tentative Specification for Copper-Nickel-Zinc Alloy Rod and Bar (B 151 - 51 T):

Section 7.—Revise as indicated above for Section 7(*a*) in Specification B 21.

Tentative Specification for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 - 51 T):

Table II.—For "B" scale Rockwell hardness values, add a footnote to read: "The Rockwell "F" scale is preferred for testing material in these tempers."

Tentative Specifications for:

Beryllium-Copper Alloy Plate, Sheet, Strip, and Rolled Bar (B 194 - 51 T),
Beryllium-Copper Alloy Rod and Bar (B 196 - 51 T), and
Beryllium-Copper Alloy Wire (B 197 - 51 T):

In the title and throughout the specifications revise "Beryllium-Copper" to read "Copper-Beryllium."

Tentative Specification for Copper-Nickel-Zinc Alloy Wire (B 206-51 T),

Section 10.—In Paragraph (*d*) revise "Table VI" to read "Table VII."

In Paragraph (*e*) revise "Table VII" to read "Tables VIII and IX."

Add a new Paragraph (*f*) to read: "(*f*) *Straightness* (*for flat wire only*).—See Section 9, Table X."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption, revisions in 27 specifications as indicated below and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specification for Copper Rods for Locomotive Staybolts (B 12 - 51):

Section 10.—Replace reference to "B 220" by "E 8."

Standard Specification for Free-Cutting Brass Rod, Bar, and Shapes for Use in Screw Machines (B 16 - 51):

Section 4.—For iron, revise present value "0.15 max" to read "0.35 max."

TABLE IV.—TENSILE AND HARDNESS REQUIREMENTS.

<table>
<tr><th rowspan="2">Temper</th><th colspan="2" rowspan="2">Nominal Diameter or Distance Between Parallel Faces, in.</th><th colspan="2">Rockwell B Hardness Determined on the Cross-Section Midway Between Surface and Center</th></tr>
<tr><th></th><th></th></tr>
<tr><td colspan="3">ROUNDS, HEXAGONS AND OCTAGONS</td><td>ROUNDS</td><td>HEXAGONS AND OCTAGONS</td></tr>
<tr><td>Soft</td><td colspan="2">Over ½</td><td>10 to 45</td><td>10 to 45</td></tr>
<tr><td>Half hard</td><td colspan="2">Over ½ to 1 incl.</td><td>60 to 80</td><td>55 to 80</td></tr>
<tr><td></td><td colspan="2">Over 1 to 2 incl.</td><td>55 to 75</td><td>45 to 70</td></tr>
<tr><td></td><td colspan="2">Over 2</td><td>50 to 70</td><td>40 to 65</td></tr>
<tr><td colspan="5">RECTANGLES AND SQUARES</td></tr>
<tr><td></td><td>Thickness, in.</td><td>Width, in.</td><td colspan="2"></td></tr>
<tr><td>Soft</td><td>Over ½</td><td>Over ½</td><td colspan="2">10 to 35</td></tr>
<tr><td>Half hard</td><td>½ and under</td><td>Over ½ to 1</td><td colspan="2">45 to 75</td></tr>
<tr><td></td><td>½ and under</td><td>Over 1 to 6</td><td colspan="2">35 to 60</td></tr>
<tr><td></td><td>Over ½ to 2</td><td>2 and under</td><td colspan="2">40 to 70</td></tr>
<tr><td></td><td>Over ½ to 2</td><td>Over 2 to 6</td><td colspan="2">35 to 60</td></tr>
<tr><td></td><td>Over 2</td><td>Over 2 to 4</td><td colspan="2">35 to 60</td></tr>
</table>

NOTE.—Rockwell tests are not established for diameters or widths less than ½ in.

Section 5(a).—Revise to read: "The material shall conform to the requirements as to tensile properties and Rockwell hardness prescribed in Table I. The Rockwell hardness tests, as far as they are prescribed, shall be the basis for acceptance of material unless agreement can not be reached. In such cases, final acceptance or rejection shall be decided by the tensile requirements."

Table I.—Revise title to read: "Tensile and Hardness Requirements," and replace the present Rockwell hardness information by the values indicated in the accompanying Table IV.

Section 6.—Revise to read as indicated above for Section 7(*a*) in Specification B 21.

Standard Specification for Bronze Castings for Bridges and Turntables (B 22 – 51):

Table II.—For alloy E add Brinell hardness requirement of 223 minimum.

Section 7.—Revise the third sentence to read: "Except for alloy E for which the load shall be 3000 kg, the load shall be 500 kg and shall be applied for 30 sec to a finished plane surface."

Section 13.—Revise to read: "13. Castings that show injurious defects revealed by machining operations subsequent to acceptance may be rejected, and if rejected, the foundry shall be notified within 30 days. The full weight of the original material rejected shall be returned to the foundry. The foundry shall not be responsible for the costs of machining defective castings."

Standard Specification for Seamless Copper Pipe, Standard Sizes (B 42 – 51), and
Standard Specification for Seamless Red Brass Pipe, Standard Sizes (B 43 – 51):

Section 9.—In the first sentence revise to read: "Each length selected in accordance with Paragraph (*a*) shall stand. . . ." and letter as Paragraph (*b*). Add a Paragraph (*a*) to read: "For the purpose of hydrostatic testing only, a number of lengths equivalent to 0.2 per cent of the shipment shall be selected at random for the following tests."

Standard Specification for Steam or Valve Bronze Castings (B 61 – 51), and
Standard Specification for Composition Brass or Ounce Metal Castings (B 62 – 51):

New Section.—Add a new Section 13 to read as indicated above for Section 13 in Specification B 22.

Standard Specifications for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 – 49):

Section 13.—Revise to read as indicated above for Section 13 in Specification B 22.

Standard Specifications for Car and Tender Journal Bearings, Lined (B 67 – 49):

Section 14.—Revise to read as indicated above for Section 13 in Specification B 22.

Standard Specification for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 – 51):

Table II.—For hard temper bars of alloys A, C, and D over 1½ to 3 in., incl, revise the present tensile strength "50,000" to read "55,000" psi, and for alloys A, C, and D bars, add yield strength requirements as follows:

Temper	Diameter or Distance Between Parallel Surfaces	Yield Strength, min, psi
Soft	All sizes	15 000
Hard	Up to 1 in., incl.	38 000
	Over 1 to 1½ in., incl.	30 000
	Over 1½ to 3 in., incl.	24 000

Section 6.—Revise to read as indicated above for Section 7(*a*) in Specification B 21.

Standard Specification for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Uses (B 100 – 49):

Table I.—For plates and sheets 20 in. and under in width and of ordered weight per square foot 20 lb or over, revise the present "Over" weight tolerance "2.0" to read "2.5."

For plates and sheets over 10 in. wide including 20 in. wide, revise the "Over" thickness tolerances to read as follows:

Ordered Thickness, In.	Thickness Tolerance, per cent Over
7/16 to 5/8, excl.	4.5
5/8 to 3/4, excl.	4.0
3/4 or over	3.5

Standard Specification for Copper and Copper - Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 51):

Section 1.—In the first sentence revise to read: ". . . various copper alloys up to 2 in., incl., in diameter for use in . . . ."

Table I.—For aluminum bronze, add copper content of "93.0, min."

For 70–30 copper-nickel, delete tin content limit of "1.5 max." Revise iron content "0.6 max" to read "0.40 to 0.70" and delete the present footnote "*d*."

For arsenical copper, add phosphorus content of "0.04 max."

Section 6.—Revise lot size to read: "600 tubes or 2000 lb or fraction of either, whichever constitutes the greater weight."

Section 16(a).—Revise the last size limit "1.500" to read "2.000."

Standard Specification for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 – 51):

Tables I, II, III and Section 5(b).—Delete alloy No. 1 and add a footnote to indicate that the alloy has been discontinued.

Standard Specifications for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 – 49):

Section 11.—Revise to read as indicated above for Section 13 in Specification B 22.

Standard Specification for Brass Wire (B 134–51):

Section 9.—In Paragraph (*d*) revise "Table V" to read "Table VI."

In Paragraph (*e*) revise "Table VII" to read "Tables VIII and IX."

Add a new Paragraph (*f*) to read: "(*f*) *Straightness (for flat wire only).*—See Section 9, Table X."

Standard Specification for Manganese Bronze Rod, Bar, and Shapes (B 138 – 51):

Sections 6 and 7(a) and Table II.—Revise as indicated above for Sections 6 and 7(*a*), and Table II respectively in Specification B 21.

Standard Specification for Leaded Red Brass (Hardware Bronze) Rod, Bar, and Shapes (B 140 – 51):

Section 6.—Revise as indicated above for Section 7(*a*) in Specification B 21.

Standard Specifications for:

Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 – 49),

High-Leaded Tin-Bronze Sand Castings (B 144 – 49),

Leaded Red Brass and Leaded Semi-Red Brass Sand Castings (B 145 – 49),

Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 49),

High-Strength Yellow Brass (Manganese Bronze) and Leaded High-Strength Yellow Brass (Leaded Manganese Bronze) Sand Castings (B 147 – 49),

Aluminum Bronze Sand Castings (B 148 – 49), and

TABLE V.—TENSILE REQUIREMENTS.

Alloy		Thickness, in.	Tensile Strength, min, psi	Yield Strength,[a] min, psi	Elongation in 2 in., min, per cent
Leaded Muntz metal		2 and under	50 000	20 000	35.0
		Over 2 to 3.5, incl.	45 000	15 000	35.0
		Over 3.5 to 5, incl.	40 000	12 000	35.0
Naval brass		3 and under	50 000	20 000	35.0
		Over 3 to 5, incl.	50 000	18 000	35.0
Admiralty metal		4 and under	45 000	15 000	35.0
Copper-nickel alloy		2.5 and under	50 000	20 000	35.0
		Over 2.5 to 5, incl.	45 000	18 000	35.0
Aluminum bronze	Alloy D	2 and under	70 000	30 000	35.0
		Over 2 to 5, incl.	65 000	28 000	35.0
	Alloy E	2 and under	90 000	36 000	10.0
		Over 2 to 5, incl.	85 000	33 000	10.0
		Over 3.5 to 5, incl.	80 000	30 000	10.0

[a] Yield strength shall be determined as the stress producing an elongation of 0.5 per cent under load, that is, 0.01 in in a gage length of 2 in.

TABLE VI.—THICKNESS TOLERANCES.

Thickness, in.	Thickness Tolerances, plus and minus, in. for Diameters or widths						
	36 in. or under	Over 36 to 60 in., incl	Over 60 to 96 in., incl	Over 96 to 132 in., incl	Over 132 to 168 in., incl	Over 168 to 204 in., incl	Over 204 to 240 in., incl
Over 1.75 to 2.00, incl.	0.050	0.055	0.062	0.065	0.067	0.070	0.080
Over 2.00 to 5.00, incl.	0.058	0.062	0.065	.....	.....	.....	.....

TABLE VII.—PHYSICAL AND ELECTRICAL REQUIREMENTS.

Temper	Diameter or Size, in.	Tensile Strength, psi		Elongation in 4 × Diameter or Thickness of Specimen, min, per cent	Bend Test, Angle of Bend, deg	Electrical Resistivity, max, ohms ((meter, gram) at 20 C (68 F))	Equivalent Electrical Conductivity, min, per cent	Rockwell Hardness, F Scale, 60-kg Load, 1/16-in. Ball
		Min	Max					
Soft	Rods:							
	Up to ⅜, incl.	...	37 000	25	180	0.15328	100.00	...
	Over ⅜	...	37 000	25	180	0.15328	100.00	50 max
	Bars, all sizes	...	37 000	25	180	0.15328	100.00	50 max
Hard	Rods:							
	Up to ⅜, incl.	40 000	...	12	120	0.15737	97.40	...
	Over ⅜ to 1, incl.	40 000	...	12	120	0.15737	97.40	80 min

Remainder of table to be retained without revision.

Leaded Nickel-Brass (Leaded Nickel-Silver) and Leaded Nickel-Bronze (Leaded Nickel-Silver) Sand Castings (B 149 – 49):

Section 17 (Except Section 16 for B 147).—Revise to read as indicated above for Section 13 in Specification B 22.

Standard Specification for Copper-Alloy Condenser Tube Plates (B 171 – 51):

Table I.—Revise "Muntz metal" to read "Leaded Muntz metal." For copper-nickel alloy, add "65.0 min" for copper content and revise iron limit of "0.6 max" to read "0.70 max."

Section 5.—Revise lot size to read:

"*Plates 1.75 in. in Thickness or Un-*

der.—A lot shall consist of not more than 5000 lb or the weight of a single plate in excess of this amount.

"*Plates over 1.75 in. in Thickness.*—A lot shall consist of not more than 10,000 lb or the weight of a single plate in excess of this amount."

Section 6.—Revise the tabulation of tensile requirements to read as shown in the accompanying Table V.

Section 10.—In Paragraph (*a*) revise "Muntz metal" to read "leaded Muntz metal."

Revise Paragraph (*b*) and add new Paragraphs (*c*) and (*d*) to read as follows relettering the present Paragraph (*c*) as Paragraph (*e*):

(*b*) The thickness tolerances for plates of copper-nickel alloy and aluminum bronze shall be 25 per cent greater than those prescribed in Table II.

(*c*) If plates are machined, the thickness tolerances shall apply to the machined portion only.

(*d*) Closer thickness tolerances than those prescribed in Table II can be furnished by surface machining. This is a special product and is subject to agreement between the manufacturer and the purchaser.

Table II.—Add tolerances to Table II as shown in the accompanying Table VI.

Section 11. Revise the second sentence to read: "The tolerances shown are the total permissible variations for plates as ordered and do not apply to the 7-in. marginal area at the edge of the plate."

Table IV.—Revise "Muntz Metal" to read "Leaded Muntz metal." Also delete the words "with machined surfaces" after "Aluminum bronze."

Standard Specification for Copper Bus Bar, Rod, and Shapes (B 187 - 51):

Section 5(a).—Revise to read as follows: "Rods up to and including $\frac{3}{8}$ in. in diameter shall conform to the requirements as to tensile strength, bend, and electrical resistivity or electrical conductivity as prescribed in Table I. Rods over $\frac{3}{8}$ in. in diameter and all bars and shapes shall conform to the requirements as to Rockwell hardness, and electrical resistivity or electrical conductivity as prescribed in Table I. For rod sizes over $\frac{3}{8}$ in. and all bars and shapes, tension and bend tests need not be made, except when specifically agreed upon at the time of placing the order, in which case they shall conform to the requirements in Table I for the properties agreed upon."

Table I.—Revise to read as shown in the accompanying Table VII.

Section 8.—In Paragraph (*a*) revise to read as indicated above for Section 7(*a*) in Specification B 21.

Add a new Paragraph (*b*) to read as follows, relettering the present Paragraph (*b*) as (*c*): "(*b*) The Rockwell test shall be made on the original longitudinal surface of the test specimen. In the case of hexagonal and octagonal rods and square bars, the Rockwell indentations shall be approximately along the center line of any one of the surfaces. For rectangular bars, the indentations shall be not less than $\frac{1}{8}$ in. from the edges of the bar."

Standard Specifications for Silicon-Bronze and Silicon-Brass Sand Castings (B 198 - 49):

Table I.—Revise the note to read: "NOTE.—All elements named in this table are normal constituents of the range of alloys contemplated in these specifications, and analysis shall be made regularly for all of them."

Section 12.—Revise to read as indicated above for Section 13 in Specification B 22.

APPENDIX

EFFECT OF SPEED OF TESTING ON THE TENSILE PROPERTIES OF COPPER AND COPPER-BASE ALLOYS*[1]

By N. H. Murdza[2]

Synopsis

This paper presents the results of a series of round-robin tension tests on copper and copper-base alloys sponsored by Subcommittee G-1 of ASTM Committee B-5 to determine the effect of testing speed on the tensile properties. The tests were made by various government (both United States and Canadian) and industrial testing laboratories throughout the country. The data presented in this paper show the effect of speed on the yield strength, tensile strength and elongation of copper and free-cutting brass rod. An analysis of the data indicates that the stressing rates used in these studies do not have any significant effect on the tensile properties, but there was considerable difficulty in controlling loading rates particularly at speeds which stressed the specimens at a rate of 60,000 psi per min or greater. The optimum rate of loading was found to be one which stressed the specimen at 30,000 psi per min for the copper and copper alloys tested.

For many years there has been a great deal of controversy among engineers and metallurgists regarding the correct and most acceptable rate of loading or stressing for the tension testing of copper and copper-base alloys. All sorts of conflicting views existed, not only among the manufacturers and consumers of nonferrous metals but likewise among the designers of tension testing equipment. This confused state of affairs has continued for more than 30 years despite the great amount of time and effort that has been expended to solve the problem Happily this confusion never retarded the advances and extraordinary improvements in the design of testing machines, but the development of the new pendulum and hydraulic testing machines merely added more machine variables whose effect had to be evaluated. The subject has attracted considerable interest among testing engineers and metallurgists and eventually these differences in testing procedures were brought to the attention of the American Society for Testing Materials.

In 1948 Subcommittee G-1 on Methods of Tests (formerly C-1) of ASTM Committee B-5 decided to investigate the effect of testing speed on the tensile properties of copper and copper-base alloys. A task group consisting of 10 members of the subcommittee was appointed to determine the effect of the speed of testing on the tensile strength, yield strength, and elongation. At that time, 13 laboratories offered to cooperate in these studies and to furnish required material (both cast and wrought).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June, 23–27, 1952.

[1] This investigation was conducted by the Task Group on Speed of Testing, Subcommittee G-1 of ASTM Committee B-5, consisting of Messrs. W. D. France, J. P. Guerard, J. J. Kanter, F. S. Mapes, J. W. Meier, N. H. Murdza, C. J. Snyder, G. Sorkin, and V. P. Weaver. It is presented in behalf of the tests group by N. H. Murdza, Chairman.

[2] Materials Engineer, Pitman-Dunn Laboratories, Frankford Arsenal, Philadelphia, Pa.

The materials furnished for these round-robin tests are listed in Table I. In brief, in these original tests each cooperating laboratory was requested to furnish all possible information on the type of tension testing machines used. The laboratories were instructed to test the materials at three different free-running crosshead speeds; 0.025, 0.250, and 0.500 in. per in. per min. In these tests each laboratory was asked to report the yield strength at both 0.5 per cent extension under load and at 0.2 per cent offset, the per cent elongation in 2 in. and the tensile strength as represented by the maximum load sustained by the specimen during test.

TABLE I.—TYPE OF COPPER AND COPPER-BASE ALLOYS USED IN FIRST (1948) ROUND-ROBIN TESTS ON EFFECT OF SPEED OF TESTING ON TENSILE PROPERTIES.

Material	ASTM Designation	Form Tested	Condition or Temper
Electrolytic tough pitch copper	B133	rod	hard-drawn
Commercial bronze (90/10)	[a]	rod	half-hard
Free-cutting brass (1 per cent Pb)	B16	rod	drawn
Free-cutting brass (3 per cent Pb)	B16	rod	drawn
Beryllium copper	B196	rod	annealed
Beryllium copper	B196	rod	drawn
Copper-silicon	B98	rod	hard
18 per cent nickel-silver	B151, Alloy 13	rod	hard
18 per cent nickel-silver	B122, Alloy 3	sheet	spring hard
Commercial bronze (90/10)	B130	sheet	annealed
Aluminum bronze	B148, Alloy 9A	casting	as-cast
Manganese bronze	B147, Alloy 8C	casting	as-cast
Gun metal (88/10/2)	B143, Alloy 1A	casting	as-cast

[a] No corresponding ASTM Designation for this alloy.

The ultimate outcome of what appeared to be a fairly comprehensive program of tension testing was disappointing. It was found that because of the different types of testing machines used in these tests, many factors affected the results so that the data could not bear any logical analysis or consistent interpretation. In passing it can only be briefly stated that none of the cooperating laboratories submitted any data on yield strength at free-running crosshead speeds of 0.250 in. per in. per min or at 0.500 in. per in. per min as these two crosshead speeds were found to be too great. In view of this evidence the task group was forced to undertake another series of round-robin tests which are now described and these tests constitute the central coverage of this paper.

SECOND SERIES OF ROUND-ROBIN TESTS ON EFFECT OF SPEED OF TESTING ON TENSILE PROPERTIES OF COPPER AND COPPER-BASE ALLOYS

As previously stated, the first round-robin tension tests proved unsuccessful because the conditions of testing and the different types of testing equipment used in these tests varied widely from one laboratory to another. As a consequence, it was not possible to unravel from this mass of data any rational or reliable conclusions.

The second series of round-robin tests were conducted under more controlled circumstances using testing equipment of essentially the same design, (hydraulic machines), the same type of extensometers, stress-strain recorders of the electromechanical type (Peters), and the same material (copper and brass rod) for the tests. All specimens conformed to the dimensions shown in Fig. 7 of ASTM Methods E 8 – 51 T,[3] (the standard round tension specimen) and were machined at the same place (Frankford Arsenal).

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[3] Tentative Methods of Tension Testing of Metallic Materials (E 8 – 51 T), 1951 Supplement to Book of ASTM Standards, Part 1, p. 375; Part 2, p. 320.

In this investigation covering the second series of round-robin tests, three U. S. Government laboratories, one Canadian Government laboratory and two industrial laboratories (one a producer and the other a consumer) cooperated in performing the tension tests. All of these tests were conducted at ambient temperature (approximately 70 F). Other laboratories offered their cooperation but participation was limited to those which had the same type of machines and extensometers.

Material Employed:

Two types of non-ferrous material were employed in this study. One was $\frac{3}{4}$-in. diameter, hard-drawn electrolytic tough pitch copper rod, per ASTM Specifications B 115 – 43[4] which was furnished by the Revere Copper and Brass Co.; the other cold-worked free-cutting brass rod per ASTM Specification B 16 – 51[3] in the same $\frac{3}{4}$-in. diameter and furnished by the Chase Brass and Copper Co. Actual analyses of these materials are shown in Table II.

TABLE II.—CHEMICAL COMPOSITION.

	Tough Pitch Copper (Electrolytic)	Free Cutting Brass
Copper, per cent	99.93	62.24
Iron, per cent	0.002	0.08
Lead, per cent	...	2.85
Tin, per cent	...	0.20
Nickel, per cent	...	0.10
Zinc, per cent	...	Remainder

The rods of both types of materials were furnished in cut lengths of approximately 7 in. These in turn were machined by the Pitman-Dunn Laboratories at Frankford Arsenal to the dimensions specified for the standard round test specimens (Fig. 7 of E 8 – 51 T). Great care was taken in machining these tension specimens. The reduced or necked-down portion of all specimens was given a No. 2 surface finish (2 microinches). The diameter of the necked-down portions of the specimens did not vary by more than plus or minus 0.0005 in.

Fortunately, before all of these tension test specimens were sent out to the cooperating laboratories, some preliminary tests were made at Frankford Arsenal on the hard-drawn copper specimens and these were found to have a yield strength of only about 700 psi under the maximum tensile strength of the material. Obviously, it would hardly be reasonable to ask the cooperating laboratories to determine yield strength values on such material at high speeds of testing and run the risk of damaging costly extensometers. In order to overcome this, all the machined 0.505-in. hard-drawn copper specimens were annealed in a non-oxidizing atmosphere at a temperature that would produce a grain size of 0.010 to 0.015 mm, in order to reduce the yield strength of the material reasonably below the tensile strength. This annealing was carried out by H. S. Freynik, Chief Metallurgist of the Riverside Metal Co. and was done in a Lindberg Cyclone Furnace of the air-circulating type. All of the hard-drawn copper specimens were annealed at 600 ±10 F for 8 hr.

The hardness of both the annealed copper and the cold-drawn free-cutting brass specimens was as follows:

	Electrolytic Annealed Copper	Free-Cutting Brass
Rockwell F Scale	64.1	...
Rockwell B Scale	...	73.4
Brinell (500 kg.)	58.5	115

To each of the cooperating laboratories, approximately twenty standard 0.505-in. tension test specimens of both the annealed copper and the free-cutting brass were furnished for the round-robin tension tests.

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[4] Standard Specifications for Electrolytic Cathode Copper (B 115 – 43), 1949 Book of ASTM Standards, Part 2, p. 338.

TABLE III.—TENSILE DATA ON ANNEALED ELECTROLYTIC COPPER.
Stress Rate—30,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongaton in 2 in., per cent	Time Interval, sec, to 3000 lb	Total Time Interval, sec, to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
LABORATORY A							
1	8 500	10 000	34 600	48.3	30.0	46.5	30 000
2	8 200	9 300	34 500	48.4	30.0	45.0	30 000
3	8 625	10 100	34 700	46.3	33.0	48.0	27 000
4	8 375	9 375	34 300	47.9	28.0	42.0	32 000
5	8 375	9 250	34 700	48.4	33.0	47.0	27 000
Average	8 415	9 605	34 560	47.8	30.8	45.7	29 200
Experimental Variation	425	850	400	2.1	5.0	6.0	5 000
LABORATORY B							
1	...	...	36 300	42.0	...	55.2	...
2	...	...	34 700	50.0	...	57.5	...
3	...	...	34 600	49.0	...	52.3	...
4	...	...	36 400	42.5	...	39.0	...
5	...	...	36 300	43.0	...	44.6	...
Average	...	...	35 700	45.3	...	49.7	...
Experimental Variation	...	...	1 800	7.5	...	18.5	...
LABORATORY C							
1	16 900	19 000	37 000	41.0	33.0	59.5	27 300
2	13 500	15 600	36 200	42.0	28.0	58.0	32 200
3	7 850	9 150	34 600	49.0	32.0	48.0	28 100
4	8 300	9 950	35 000	49.0	33.0	50.0	27 300
5	9 800	11 400	35 800	46.5	32.5	49.5	27 700
Average	11 270	13 020	35 720	45.5	31.7	53.0	28 520
Experimental Variation	9 050	9 850	2 400	8.0	5.0	11.5	4 900
LABORATORY D							
1	8 380	9 500	34 500	48.5	32.0	68.0	28 140
2	10 750	12 120	35 500	46.5	31.0	87.0	29 030
3	9 250	10 720	34 750	46.0	32.0	63.0	28 140
4	13 800	19 880	36 910	39.0	27.0	70.0	33 200
5	14 250	16 000	36 250	42.0	28.0	67.0	32 150
Average	11 290	13 640	35 600	44.4	30.0	71.0	30 130
Experimental Variation	5 870	10 380	2 360	9.5	5.0	24.0	5 060
LABORATORY E							
1	10 500	11 970	34 450	47.0	40.0	...	30 000
2	12 000	14 550	34 900	46.0	30.0	...	30 000
3	10 000	11 200	34 650	48.0	30.0	...	30 000
4	7 780	8 980	34 450	50.0	30.0	...	30 000
5	9 300	11 500	34 850	47.0	30.0	...	30 000
Average	9 915	11 640	34 660	47.7	32.0	...	30 000
Experimental Variation	4 220	5 570	450	4.0	10.0	...	...
LABORATORY F							
1	10 000	12 500	35 000	48.0	...	66.5	30 000
2	8 750	10 400	34 400	47.0	...	54.5	23 400
3	8 600	10 300	34 500	49.0	...	53.0	28 200
4	8 400	9 900	34 100	50.0	...	50.5	29 500
5	11 700	14 125	35 100	46.0	...	66.0	30 700
Average	9 490	11 445	34 620	48.0	...	58.1	28 360
Experimental Variation	3 300	4 225	1 000	4.0	...	16.0	7 300

(Continued on pages 182 and 183.)

TABLE III.—*Continued*

Stress Rate—60,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongation in 2 in., per cent	Time Interval, sec, to 3000 lb	Total Time Interval, sec, to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
			LABORATORY A				
1	7 450	8 625	34 400	49.8	15.0	29.0	60 000
2	10 000	11 200	35 700	47.4	16.5	30.5	54 500
3	7 750	9 000	34 600	48.9	14.5	28.5	62 000
4	9 550	11 125	35 400	46.5	15.0	29.0	60 000
5	11 550	12 950	35 600	45.4	15.5	32.5	57 000
Average	9 200	10 580	35 140	47.6	15.3	29.9	58 700
Experimental Variation	4 100	4 325	1 300	4.4	2.0	4.5	7 500
			LABORATORY B				
1	...	...	34 800	47.5	...	42.7	...
2	...	...	36 600	40.0	...	34.6	...
3	...	...	35 100	46.5	...	40.5	...
4	...	...	34 800	49.0	...	42.6	...
5	...	...	36 500	42.0	...	41.3	...
Average	...	...	35 600	45.0	...	40.3	...
Experimental Variation	...	...	1 800	9.0	...	8.1	...
			LABORATORY C				
1	8 300	10 300	34 800	48.0	16.5	33.5	54 600
2	17 700	19 800	37 500	39.0	14.5	29.5	62 100
3	8 500	10 300	34 900	47.0	17.0	33.0	53 000
4	19 300	21 250	37 500	39.5	16.0	31.0	56 200
5	13 250	15 700	36 500	42.5	17.0	34.0	53 000
Average	13 410	15 470	36 240	43.2	16.2	32.5	55 780
Experimental Variation	11 300	10 950	2 700	9.0	2.5	4.5	9 100
			LABORATORY D				
1	9 950	12 080	34 860	46.0	15.0	51.0	59 700
2	11 620	12 750	36 500	41.5	15.0	52.0	60 000
3	9 950	11 690	34 860	46.0	15.0	47.0	59 700
4	8 500	11 000	34 600	48.0	16.0	45.0	56 250
5	8 830	11 810	34 380	48.0	16.0	40.0	55 950
Average	9 770	11 870	35 040	45.9	15.4	47.0	58 320
Experimental Variation	3 120	1 750	2 120	6.5	1.0	12.0	4 050
			LABORATORY E				
			No data were submitted				
			LABORATORY F				
1	8 600	13 100	34 300	49.5	...	40.0	57 300
2	11 000	10 400	34 400	45.5	...	37.5	52 400
3	12 100	...	35 450	45.5	...	38.0	70 000
4	9 700	...	35 400	49.0	...	39.0	70 500
5	11 100	...	34 700	45.0	...	41.0	86 200
Average	10 500	11 750	34 850	46.9	...	39.1	67 280
Experimental Variation	3 500	2 700	1 400	4.5	...	3.5	33 800

TABLE III.—*Continued*
Stress Rate—90,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongation in 2 in., per cent	Time Interval, sec, to 3000 lb	Total Time Interval, sec to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
LABORATORY A							
1	9 700	11 375	35 500	47.1	7.0	12.0	85 500
2	7 125	8 375	34 600	48.8	6.5	17.0	92 000
3	11 375	11 500	36 100	44.4	7.0	15.0	85 500
4	8 750	10 250	35 300	47.1	7.0	14.5	85 500
5	16 250	18 000	37 100	41.0	6.5	12.5	92 000
Average	10 640	11 900	35 720	45.6	6.8	14.2	88 100
Experimental Variation	9 125	9 635	2 500	4.4	0.5	5.0	6 500
LABORATORY B							
1	...	...	35 700	44.5	...	47.5	...
2	...	...	35 900	46.0	...	49.2	...
3	...	...	35 100	48.5	...	34.0	...
4	...	...	35 100	48.5	...	58.3	...
5	...	...	35 400	46.0	...	37.0	...
Average	...	...	35 400	46.7	...	45.3	...
Experimental Variation	...	...	800	4.0	...	24.3	...
LABORATORY C							
1	8 300	10 500	34 900	48.5	11.0	27.0	82 000
2	9 250	12 000	35 500	48.0	10.5	25.5	86 000
3	10 300	13 600	35 900	47.5	10.0	25.0	90 000
4	16 700	19 000	37 000	41.5	10.0	26.0	90 000
5	13 250	16 000	36 300	43.0	10.5	25.5	85 000
Average	11 550	14 220	35 920	45.7	10.4	25.8	86 760
Experimental Variation	8 400	8 500	2 100	7.0	1.0	2.0	8 000
LABORATORY D							
1	15 170	16 530	35 230	46.0	9.0	35.0	99 500
2	9 200	11 810	34 670	47.5	12.0	35.0	74 620
3	8 950	11 810	34 290	48.5	11.0	37.0	81 400
4	12 880	15 000	35 500	46.5	9.0	38.0	100 000
5	11 810	14 670	35 620	45.5	10.0	39.0	89 550
Average	11 600	13 960	35 060	46.8	10.2	36.8	89 010
Experimental Variation	6 220	4 720	1 330	3.0	3.0	4.0	25 380
LABORATORY E							
No data were submitted							
LABORATORY F							
No data were submitted							

Testing Procedure:

The six cooperating laboratories were given specific instructions with regards to the testing procedure to follow so that every laboratory would be employing precisely the same method in these round-robin tests.

It was first planned to use uniform rates of strain. However, to accomplish this, it was found necessary for each laboratory to have a strain-rate pacer to control uniform rates of strain. A survey revealed that only two cooperating laboratories had such a strain-rate pacer; namely, Frankford Arsenal and the Canada Department of Mines and

TABLE IV.—TENSILE DATA ON FREE-CUTTING BRASS.
Stress Rate—30,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongation in 2 in., per cent	Time Interval, sec, to 10,000 lb	Total Time Interval, sec, to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
LABORATORY A							
1	50 750	44 500	59 800	18.9	96.0	102.5	31 200
2	50 000	45 000	60 500	19.4	98.0	105.0	30 500
3	49 000	42 500	59 000	19.1	102.0	107.0	29 400
4	51 500	46 000	61 800	17.3	98.0	106.0	30 500
5	50 000	42 500	59 500	19.1	102.0	108.0	29 400
Average	50 250	44 100	60 120	18.7	99.2	105.7	30 200
Experimental Variation	2 500	3 500	2 800	2.1	6.0	5.5	1 800
LABORATORY B							
1	51 325	44 400	59 500	19.0	102.2	111.2	29 350
2	50 050	40 900	59 000	19.5	101.2	112.8	29 640
3	48 925	40 250	59 000	19.5	99.1	109.8	30 270
4	48 425	41 425	60 600	20.0	100.6	110.4	30 150
5	47 050	40 800	59 500	20.0	99.5	110.0	29 830
Average	49 155	41 555	59 520	19.6	100.5	110.8	29 850
Experimental Variation	4 275	4 150	1 600	1.0	1.9	2.8	920
LABORATORY C							
1	52 000	44 400	60 200	17.0	97.0	120.5	30 900
2	50 600	44 400	60 300	19.0	98.0	116.5	30 600
3	49 500	43 600	59 200	18.5	99.0	116.0	30 300
4	48 300	40 500	57 900	19.0	100.0	114.0	30 000
5	50 100	42 200	59 000	19.5	99.0	113.0	30 300
Average	50 100	43 775	59 320	18.6	98.6	116.0	30 420
Experimental Variation	3 700	3 900	2 400	2.5	3.0	7.5	900
LABORATORY D							
1	48 000	41 000	58 900	19.0	99.0	115.0	30 150
2	49 200	43 000	61 500	17.5	101.0	120.0	29 550
3	50 300	43 700	60 500	18.0	101.0	118.0	29 700
4	49 100	40 000	59 400	17.0	101.0	116.0	29 700
5	50 750	39 750	60 000	17.9	99.0	115.0	30 300
Average	49 470	41 490	60 060	16.5	100.2	116.8	29 880
Experimental Variation	2 750	3 700	2 600	1.5	2.0	5.0	750
LABORATORY E							
1	46 800	37 700	59 000	18.5	90.0	140.0	30 000
2	...	...	58 400	17.5	90.0	130.0	30 000
3	46 300	38 200	59 400	18.0	90.0	125.0	30 000
4	49 200	42 000	60 400	18.5	105.0	152.0	30 000
5	51 300	41 400	59 900	18.5	105.0	150.0	30 000
Average	48 400	39 850	59 420	18.2	96.0	139.4	30 000
Experimental Variation	5 000	4 300	2 000	1.0	15.0	27.0	...
LABORATORY F							
1	52 700	44 400	60 400	19.0	...	114.0	30 300
2	51 000	42 600	59 400	19.0	...	108.5	30 200
3	49 600	41 400	59 400	20.0	...	108.5	29 100
4	49 100	42 500	58 900	19.0	...	148.0	29 100
5	50 000	41 000	59 400	18.0	...	109.0	28 900
Average	50 480	42 380	59 500	19.0	...	117.6	29 520
Experimental Variation	3 600	3 400	500	2.0	...	39.5	1 400

TABLE IV.—*Continued*

Stress Rate—60,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongation in 2 in., per cent	Time Interval, sec, to 10,000 lb	Total Time Interval, sec, to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
LABORATORY A							
1	50 500	43 500	61 900	17.5	46.0	54.5	65 000
2	50 750	45 000	61 900	18.8	48.0	56.5	62 000
3	50 500	44 500	60 800	19.2	49.0	55.5	61 000
4	49 250	42 000	58 800	19.5	49.0	55.5	61 000
5	49 500	42 000	59 300	19.5	48.0	55.0	62 000
Average	50 100	43 400	60 540	18.9	48.0	55.4	62 200
Experimental Variation	1 500	3 000	3 100	2.0	3.0	2.0	4 000
LABORATORY B							
1	48 900	40 800	59 500	19.5	52.3	64.0	57 360
2	48 900	37 750	59 000	19.5	45.5	57.1	65 930
3	48 400	40 875	59 000	19.5	52.3	61.8	57 360
4	49 925	43 700	60 600	19.5	52.0	61.0	57 690
5	48 425	41 675	59 500	19.5	50.0	59.5	60 000
Average	48 910	40 960	59 520	19.5	50.4	60.7	59 670
Experimental Variation	1 525	4 125	1 600	0.0	6.8	6.9	2 640
LABORATORY C							
1	49 600	40 300	58 500	19.5	51.0	64.0	58 800
2	50 900	43 300	62 400	17.0	49.0	62.5	61 200
3	49 500	43 400	61 200	18.5	53.0	68.0	56 600
4	47 900	42 500	59 200	18.5	54.0	71.0	55 600
5	49 300	43 300	59 500	19.0	48.0	62.0	62 400
Average	49 440	42 560	60 160	18.5	51.0	65.5	58 920
Experimental Variation	3 000	3 100	3 900	2.5	5.0	9.0	6 800
LABORATORY D							
1	49 500	41 750	60 000	16.5	50.0	63.0	60 000
2	49 000	41 250	59 750	18.5	51.0	63.0	58 800
3	49 750	40 750	60 250	18.5	50.0	62.0	60 000
4	48 250	42 000	59 150	19.5	50.0	65.0	60 000
5	49 050	41 900	59 800	18.0	51.0	63.0	58 800
Average	49 110	41 530	59 790	18.2	50.4	63.2	59 510
Experimental Variation	1 500	750	1 100	3.0	1.0	3.0	1 200
LABORATORY E							
1	49 500	40 000	61 400	17.5	52.0	58.0	60 000
2	50 300	38 900	58 400	18.0	54.0	49.0	60 000
3	50 300	41 800	59 400	18.5	52.0	52.0	60 000
4	49 100	40 600	58 700	18.0	54.0	55.0	60 000
5	50 200	37 100	61 900	16.5	53.0	46.0	60 000
Average	49 880	39 680	59 960	17.7	53.0	52.0	60 000
Experimental Variation	1 200	4 700	3 500	2.0	2.0	12.0	...
LABORATORY F							
1	51 800	42 700	58 900	19.0	...	53.5	69 300
2	52 400	44 400	59 900	19.0	...	61.5	61 200
3	50 900	42 300	58 900	19.0	...	63.5	58 600
4	51 200	43 000	58 700	19.0	...	61.0	64 400
5	48 700	42 200	59 400	19.5	...	60.0	64 000
Average	51 000	42 920	59 160	19.1	...	59.9	63 500
Experimental Variation	3 700	2 200	1 200	0.5	...	3.5	5 800

(Continued on page 186.)

TABLE IV.—*Continued*

Stress Rate—90,000 psi per min

Specimen	Yield Strength, psi		Tensile Strength, psi	Elongation in 2 in., per cent	Time Interval, sec, to 10,000 lb	Total Time Interval, sec, to Break	Calculated Stress Rate, psi per min
	0.2 per cent Offset	0.5 per cent Extension Under Load					
LABORATORY A							
1	50 500	44 000	61 300	18.1	34.0	55.0	88 000
2	52 000	44 500	60 300	19.1	33.0	48.0	90 900
3	49 750	42 500	59 200	18.8	34.0	52.0	88 000
4	49 000	42 500	59 400	19.0	35.0	53.0	85 500
5	50 750	43 250	61 800	17.4	32.0	46.0	93 600
Average	50 400	43 350	60 400	18.4	33.6	50.8	89 200
Experimental Variation	3 000	2 000	2 600	1.7	3.0	9.0	8 100
LABORATORY B							
1	...	...	61 500	18.0	...	35.1	...
2	...	...	59 000	18.5	...	30.0	...
3	...	...	58 500	20.0	...	38.3	...
4	...	...	59 000	19.5	...	25.4	...
5	...	...	58 900	20.0	...	36.0	...
Average	...	...	59 400	19.2	...	33.0	...
Experimental Variation	...	...	3 000	2.0	...	10.6	...
LABORATORY C							
1	49 000	43 700	61 200	19.0	34.4	45.4	87 000
2	49 500	42 900	59 400	18.5	33.5	43.5	89 600
3	49 700	44 400	60 600	19.0	33.0	47.0	90 900
4	51 300	44 600	60 000	19.0	34.5	45.0	88 200
5	48 900	41 300	58 800	19.0	33.5	42.5	89 600
Average	49 680	43 380	60 000	18.9	33.7	44.7	89 060
Experimental Variation	2 400	3 300	2 400	0.5	1.5	4.5	3 900
LABORATORY D							
1	50 500	40 500	59 600	17.5	37.0	52.0	80 700
2	49 750	42 000	59 900	17.5	36.0	49.0	83 400
3	48 500	41 250	59 500	18.5	33.0	45.0	90 950
4	49 250	42 000	59 250	18.5	34.0	50.0	88 400
5	50 500	38 750	59 250	18.5	33.0	48.0	90 950
Average	49 700	40 880	59 500	18.1	34.6	48.8	86 880
Experimental Variation	2 000	3 250	650	1.0	4.0	7.0	1 025
LABORATORY E							
1	48 400	40 000	58 400	19.0	35.0	58.0	90 000
2	50 300	35 900	59 000	17.5	38.0	56.0	90 000
3	50 300	39 400	60 400	19.0	36.0	52.0	90 000
4	48 600	37 600	59 700	17.5	38.0	48.0	90 000
5	50 300	41 700	59 400	17.0	39.0	48.0	90 000
Average	49 580	39 286	59 380	18.0	37.2	52.4	90 000
Experimental Variation	7 900	4 100	1 300	2.0	4.0	10.0	...
LABORATORY F							
1	50 000	43 500	59 400	18.0	...	44.0	93 100
2	49 400	42 400	58 900	18.0	...	48.0	92 900
3	47 700	42 500	58 400	20.0	...	...	94 900
4	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...
Average	49 033	42 800	58 900	18.6	...	46.0	93 633
Experimental Variation	2 300	1 100	1 000	2.0	...	2.0	2 000

Technical Surveys, Mines Branch. Under these circumstances, it was clear that uniform rates of strain could not be employed by all cooperating laboratories; consequently the only alternative was the use of uniform stressing rates. As a consequence, each laboratory was asked to pull the specimens at stressing rates of 30,000, 60,000, and 90,000 psi per min which roughly corresponded to strain-rates of 0.002, 0.004, and 0.006 in. per in. per min (based on arbitrary modulus of 15,000,000 psi).

Each laboratory was further requested to use the most exacting means for controlling stress rates. If the tension testing machine was not provided with load-pacing facilities then the use of a stop watch was allowed for timing the prescribed stressing speed. Furthermore, all the testing machines used in these tests were of the hydraulic type so that machine variables in this second series of tests might be reduced to a minimum.

Each testing laboratory was asked to furnish the following information:

1. Approximate stress rate (load-pacing dial rate, if facilities are available).
2. Time in seconds up to initial load of 3000 lb for the annealed copper and 10,000 lb for the free-cutting brass.
3. Time in seconds to the breaking point.
4. Yield strength in pounds per square inch both for 0.2 per cent offset, and for 0.5 per cent extension under load.
5. Tensile strength in pounds per square inch (maximum tensile stress sustained by the specimen).
6. Elongation in 2 in. in per cent.
7. Records of the stress-strain curve obtained for each specimen tested.

Discussion of Results:

The results from all the cooperating laboratories were tabulated for each type of material tested, and are shown in Tables III and IV.

The physical results on five specimens which were tested at each of the three stressing rates by all six cooperating laboratories were averaged, and extreme variations are shown in the tables which are included in this paper. As stated before, each laboratory was asked to submit autographic graphs of the stress-strain curves obtained for each specimen tested but only two laboratories did so. No typical examples of the stress-strain curves are included in this paper because it was felt that they added nothing of value.

The averages of the yield strength, by both the offset and extension under load methods, the tensile strength and the per cent elongation were plotted and are shown on Figs. 1 and 2. Most of these graphic representations are complete except Fig. 1 where the yield strengths by the two different methods are not shown for the annealed copper. In Fig. 2 only the yield strength values at stressing rates of 30,000 and 60,000 psi are plotted for free-cutting brass because no data were submitted for a stress rate of 90,000 psi per min probably because of difficulty in maintaining either the required stress rate or lack of ability of the stress-strain recording mechanism to follow accurately the automatic recording of the stress-strain relationship at the higher speed of stressing.

It appears that there was considerable trouble in most of the cooperating laboratories in maintaining the desired uniformity in rate of stress application, especially at the higher rates of loading. In these tension tests, it was aimed to have every cooperating laboratory stress the specimens at 30,000, 60,000, and 90,000 psi per min. Actual tests showed, however, that the maximum deviations

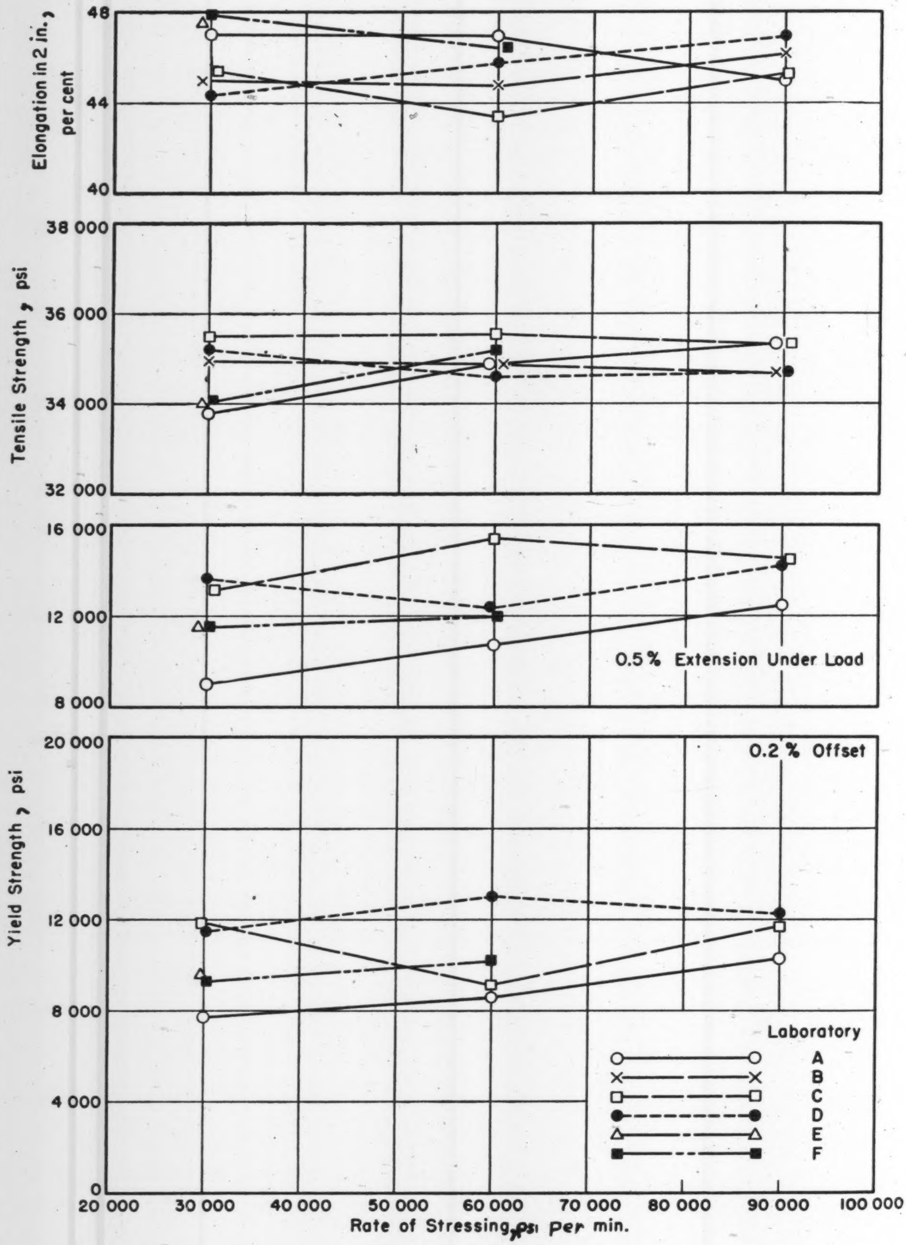

FIG. 1.—Effect of Rate of Stressing on Tensile and Yield Strength of Annealed Electrolytic Copper.

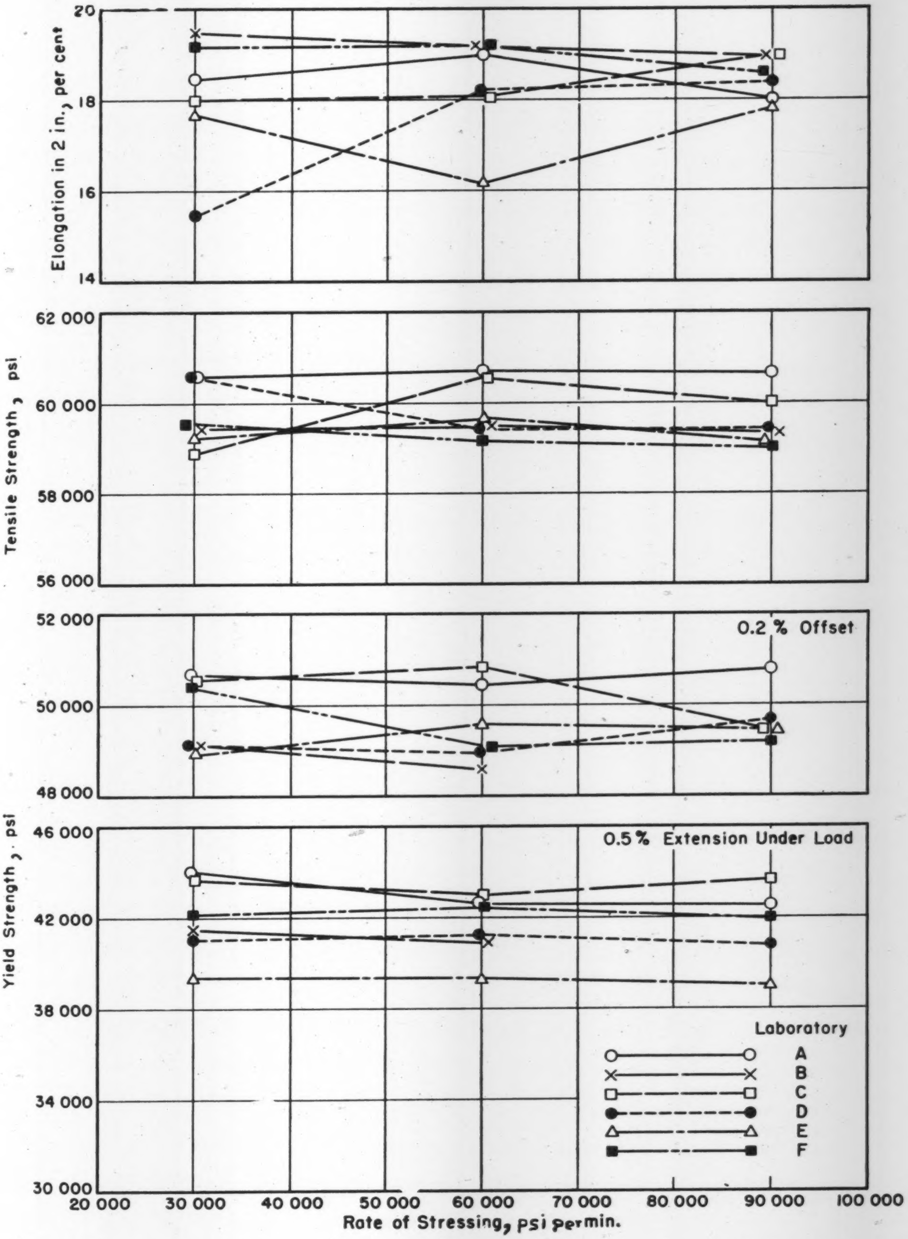

FIG. 2.—Effect of Rate of Stressing on Tensile and Yield Strength of Cold-Drawn Free-Cutting Brass Rod.

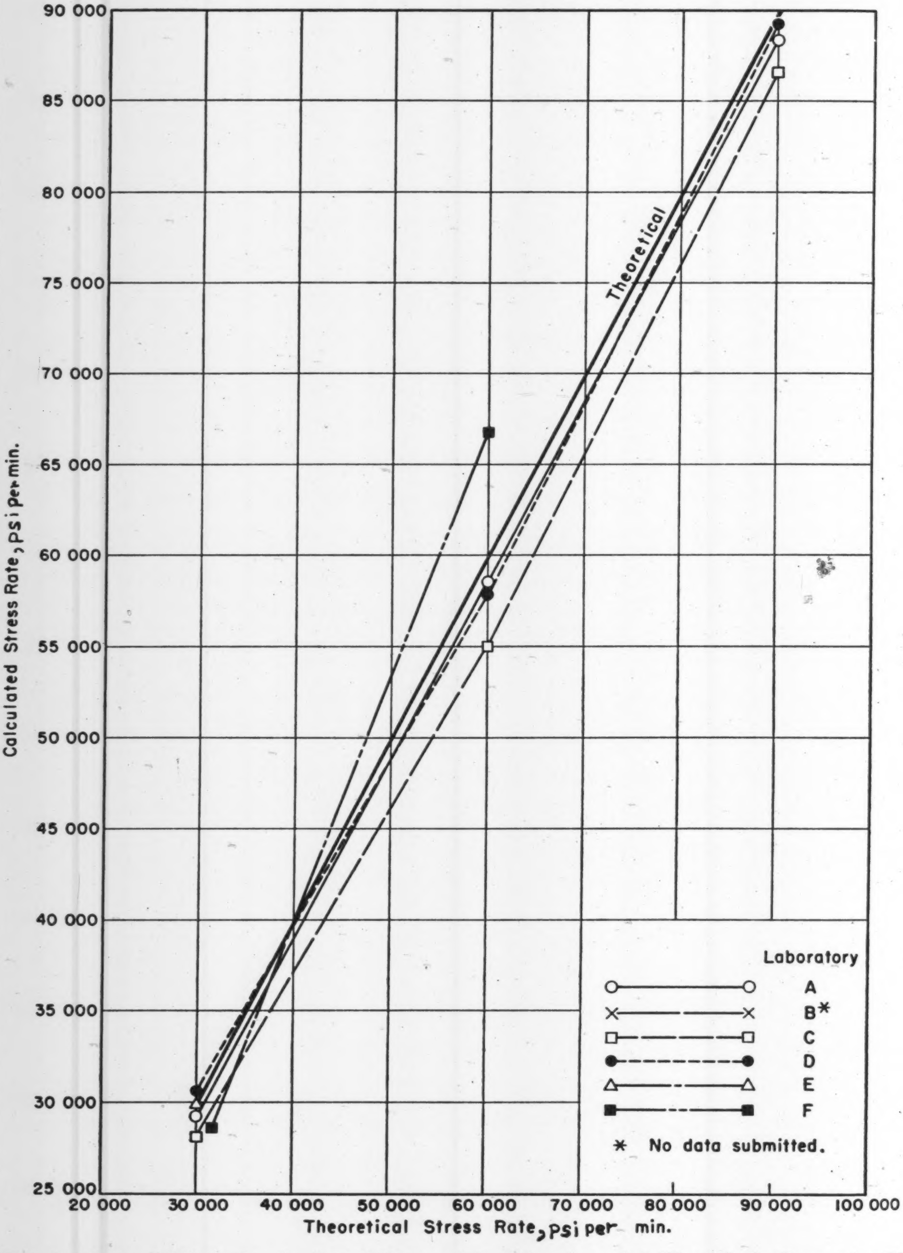

FIG. 3.—Over-all Dispersion in Actual Rates of Stressing Annealed Electrolytic Copper by Different Cooperating Laboratories.

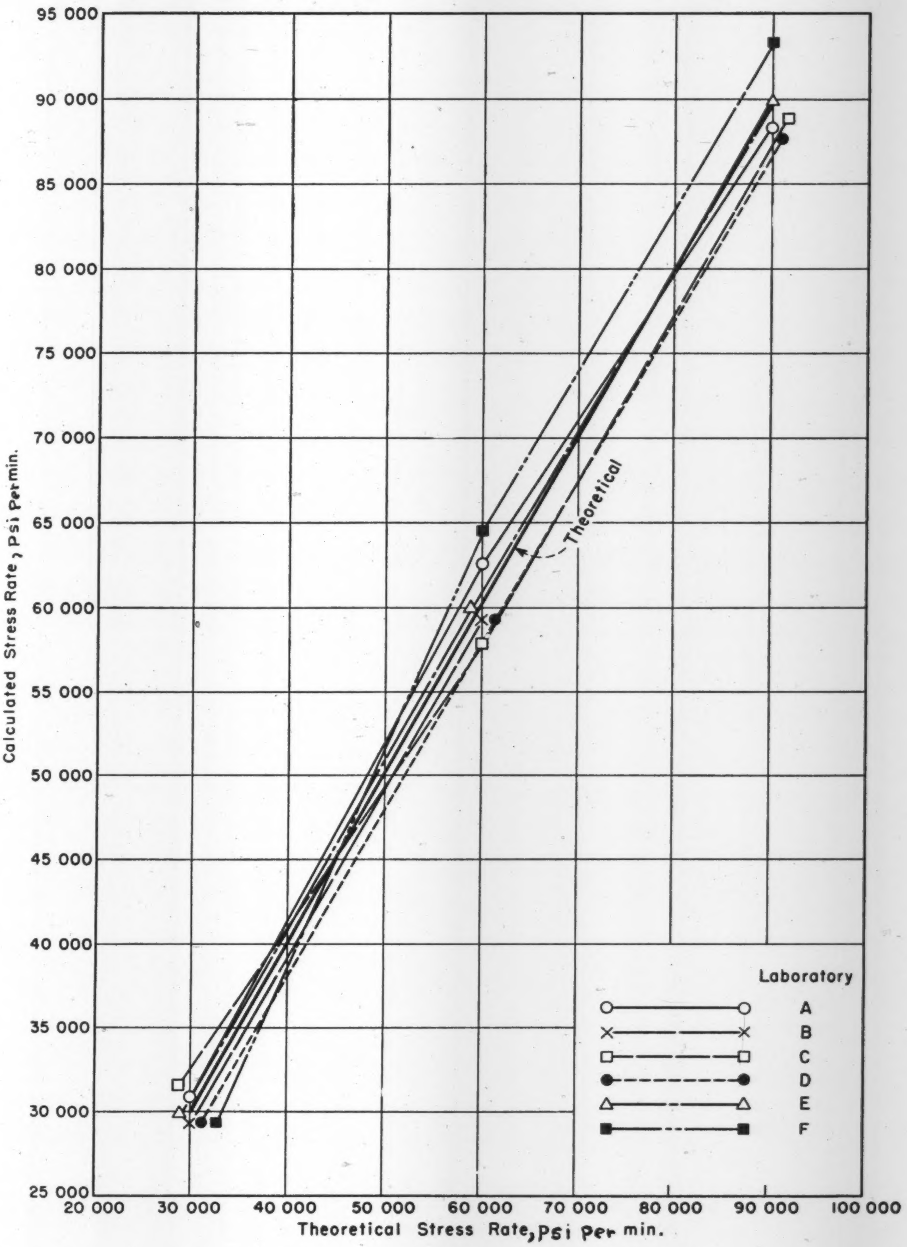

FIG. 4.—Over-all Dispersion in Actual Rates of Stressing Cold-Drawn Free-Cutting Brass Rod by Different Cooperating Laboratories.

from the theoretical stress rates were as follows (see Figs. 3 and 4):

Theoretical Stress Rate, psi per min	Maximum Deviation, psi per min	
	Annealed Copper	Brass
30 000	−1640	+420
60 000	+7280	+3500
90 000	−3240	+3633

At this point, it might be well to cite the following pertinent facts that have been abstracted from the report submitted by the Naval Engineering Experiment Station as the result of their findings in making these round-robin tests. The report stated that:

"All tests were conducted on a hydraulic testing machine equipped with 10,000- and 100,000-lb scales. The 10,000-lb range was used for the tests on the copper specimens, and the 100,000-lb range for the brass specimens.

"Detailed instructions regarding the testing speeds were given by the subcommittee. The Station interpreted these instructions to mean that the object was to test the specimens at 30,000, 60,000 and 90,000 psi per min up to the yield strength, and at 90,000 psi per min from the yield strength to ultimate failure.

"The Station found that the initial loading was not controllable because of the seating of the specimen, play of the crossheads, and some necessary readjustment of the machine controls. It was also found that testing conditions settled down after the first 500 to 1,000 lb of stress had been applied. From this point on, the loading rate was maintained practically constant up to the yield strength.

"The three desired loading rates up to the yield strength (0.5 per cent extension under load) were obtained successfully in the case of the brass but not in the case of the copper. The yield strength value was so low that attempts at adjusting the machine to the desired loading rates were not successful. It was the Station's opinion that a loading rate of 30,000 psi per min is the maximum practicable rate for tests on annealed copper.

"The Station found that the loading rate beyond the yield strength fell far short of the desired rate of 90,000 psi per min in most cases. In making the tests it was found that the testing machine would not consistently load with this stressing speed when the specimens were well within the plastic range, even though the loading valve was turned wide open. As the load-strain curve began to flatten out near the ultimate load, the rapid increase of strain rate with a small increase of load required continuous manipulation of the loading controls in order to keep a fairly constant loading rate. It was found that a reasonably constant loading rate would be maintained only at rates far below 90,000 psi per min.

"It was the Station's opinion that the specified loading rate beyond the yield strength is not practicable. The only way that uniformity between specimens could be provided with most testing machines would be to use a constant crosshead speed, or a much lower loading rate within the plastic range.

"At the very high loading rates, an appreciable discrepancy was noted between the load shown by the stress-strain recording instrument and the load shown by the load indicator of the hydraulic testing machine. The stress-strain recording instrument read higher loads in this case. It was believed that the recorder was correct while the hydraulic machine indicator was in error due to inertia lag of the weighing system. If the loading rate was allowed to fall off, the weighing system of the hydraulic machine then caught up with the stress-strain recorder."

CONCLUSIONS

Tension tests made on 0.505-in. diameter machined annealed electrolytic tough pitch copper and hard-drawn free-cutting brass rod to determine the effect of speed of testing at three different rates of stressing indicate that:

1. Rate of stressing at testing speeds of approximately 30,000, 60,000 and 90,000 psi per min (roughly corresponding to strain rates of 0.002, 0.004 and 0.006 in. per in. per min respectively) does not appear to have any effect on the yield strength values using the 0.2 per cent offset method or the 0.5 per cent extension under load method.
2. Stressing rates varying from 30,000 to 90,000 psi per min did not appear to have any significant or critical influence on the tension test results.
3. The yield strength using the 0.5 per cent extension under load method at the different rates of stress consistently showed a value about 1250 psi higher than the yield strength values obtained by the 0.2 per cent offset method on the annealed electrolytic copper having 0.010 to 0.015 mm grain size; and conversely, the yield strength for the free-cutting brass rod by the 0.5 per cent extension under load method at different rates of stressing consistently was about 7000 psi lower than the yield strength values obtained by the 0.2 per cent offset method.
4. There seemed to be no consistency between cooperating laboratories in reporting the time interval for the specimens to fracture. This appeared to indicate that there was a wide variation in the actual rate of stress even when it was believed that the testing speed was fixed at a specified rate. It further appeared that no satisfactory control over the rate of stressing can be maintained when once the rate of stress was set, particularly with the current hydraulic type of tension testing equipment used in the different laboratories.
5. At rates of stressing above 30,000 psi per min, especially on copper, considerable difficulty was experienced in obtaining satisfactory yield strength values by recording the stress-strain relationship autographically when the material was stressed at rates of 60,000 to 90,000 psi per min.
6. The general deduction can be drawn from all the tension tests that to obtain a satisfactory autographic stress-strain curve for yield strength determinations a stress rate of 30,000 psi per min is about the maximum, although some discretion must be used if this stress rate is used on annealed copper. It is suggested, therefore, that the rate of stressing for the determination of yield strength by the 0.2 per cent offset and the 0.5 per cent extension under load methods should be not over 30,000 psi per min using automatic means of stress-strain recording.
7. It can be said that all of the tensile values recorded by the six cooperating laboratories on both the annealed copper and free-cutting hard-drawn brass were surprisingly consistent.

Acknowledgment:

The Task Group on the Speed of Testing wishes to express its grateful acknowledgments to the U. S. Experimental Engineering Station of the Navy Department, the General Electric Co., the Canada Department of Mines and Technical Surveys, the Bridgeport Brass Co., and the National Bureau of Standards, for the generous cooperation they extended in making the tests; to Frankford Arsenal for preparing the test specimens; and to the Chase Brass and Copper Co. and to the Revere Copper and Brass, Inc. for supplying the material for the tests.

REPORT OF COMMITTEE B-6
ON
DIE-CAST METALS AND ALLOYS*

Committee B-6 held two meetings during the year: one in Atlantic City, N. J., on June 20, 1951, and one in Cleveland, Ohio, on March 5, 1952.

There is a balance of $2645.56 in the funds of Committee B-6, as of December 31, 1951.

At the present time, the committee consists of 93 members, of whom 44 are classified as producers, 23 as consumers, and 26 as general interest members.

Mr. J. R. Townsend has found it necessary to discontinue his activities as chairman of Committee B-6, a post he has filled with honor and distinction for the past 18 years. By unanimous vote, the members of the committee wish to record their deep appreciation of his long, active, and expert service. In recognition of his work, the committee has elected Mr. Townsend its first Honorary Chairman Emeritus.

The election of officers for the ensuing term of two years resulted in selection of the following:

Chairman, W. Babington.
Vice-Chairman, A. E. Weiss.
Secretary, G. L. Werley.

A number of recommendations are being presented, for the most part detailing the action reported a year ago[1] incorporating the Committee B-7 code identification B 275 – 52 T in various specifications for die-casting alloys.

REVISION OF TENTATIVES

The committee recommends revisions in the following two tentative specifications: Tentative Specifications for Aluminum-Base Alloy Die Castings (**B 85 – 50 T**):[2] Incorporation of the Committee B-7 code identification system for aluminum alloy die castings in this specification.

Tentative Specifications for Zinc-Base Alloys in Ingot Form for Die Castings (**B 240 – 49 T**):[3] Incorporation of the Committee B-7 code identification system, in conjunction with the present markings, for zinc die casting alloys in this specification.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Magnesium-Base Alloy Die Castings (**B 94 – 49 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard, with the following revision: Incorporation of the Committee B-7 code identification system for the magnesium alloy die castings in this specification.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following three standard specifications and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 168 (1951).

[2] 1950 Supplement to Book of ASTM Standards, Part 2.

[3] 1949 Book of ASTM Standards, Part 2.

Standard Specifications for Zinc-Base Alloy Die Castings (**B 86 – 48**):[3] Incorporation of the Committee B-7 code identification system, in conjunction with the present markings, for the zinc alloy die castings in this specification.

Standard Specifications for Lead- and Tin-Base Alloy Die Castings (**B 102 – 48**):[3] Incorporation of the Committee B-7 code identification system for the lead- and tin-base alloy die castings in this specification.

Standard Specifications for Copper-Base (Brass) Alloy Die Castings (**B 176 – 50**):[3] Incorporation of the Committee B-7 code identification system for the brass alloy die castings in this specification.

The Committee B-7 code identification system was referred to in last year's report and approved by letter ballot of the committee. The other recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die Casting Alloys (E. V. Blackmun, chairman) reports the completion of the testing of alloys G2, G3, SG2, and SG3 after five years of outdoor exposure for both the Sandy Hook, N. J., and the New York City sites. Similar test specimens are being continued on exposure for a 10-yr period at New York.

A task group, working in conjunction with Committee B-7 on Light Metals and Alloys, agreed to some iron and zinc limit changes in several aluminum ingot alloys in the interest of increasing the amount of available material without affecting the industries' ability to produce castings to meet the B 85 die casting specifications. These changes have been approved by letter ballot of Committee B-7, and have been incorporated in the Tentative Specifications B 179 – 51 T.

Increased demand by users of aluminum and magnesium castings for a guide in the selection of alloys for particular applications led to the establishment of an Alloy Recommendation Committee by the American Foundrymen's Society. This committee has developed various tabular forms for ready presentation of such data for sand, permanent mold, and die-casting alloys. Subcommittee I is considering now the advisability of including a similar tabulation for the die-casting alloys in the Appendix to the Tentative Specifications B 85, and of making such revisions in the typical mechanical properties of the alloys as are in line with more recent data.

Subcommittee II on Zinc-Base Die-Casting Alloys (A. E. Weiss, chairman). —The Task Group charged with the setting of limits for tramp elements in zinc die castings has tentatively set maximum values for nickel, chromium and manganese but not for silicon. It may be necessary to conduct some experimental tests to set the silicon limit because the available information indicates that the safe maximum value is between 0.015 and 0.08 per cent, and zinc die castings sometimes contain more than 0.015 per cent silicon.

Subcommittee V on Exposure and Corrosion Tests (Sam Tour, chairman).— The last remaining outdoor rack at Key West, Fla., containing magnesium and zinc alloy test bars scheduled for testing in 1959, has been moved to a new location in Key West. Specimens now on exposure at Sandy Hook, N. J., have been damaged or destroyed beyond use.

Subcommittee V has been instructed

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

to conduct atmospheric exposure tests on the extra specimens prepared in the program from which it has concluded, on the basis of mechanical property tests, that the zinc limit in aluminum alloys SC5 and SC6 could be raised safely from 0.6 to 1.0 per cent.

Subcommittee IX on Die-Casting Processes (A. E. Martin, chairman) has received written discussions on the paper entitled "Aluminum Die Castings—The Effect of Process Variables on Their Properties"[5] by W. Babington and D. H. Kleppinger. These are being published with this report.[6]

The subcommittee is currently studying a paper prepared by Bruno Sachs on "The Mechanics and Mathematics of the Die Casting Process."[7]

This report has been submitted to letter ballot of the committee, which consists of 93 members; 88 members returned their ballots, of whom 83 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

G. L. WERLEY,
Secretary.

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[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 169 (1951).

[6] See p. 197.

[7] Submitted for publication in the ASTM BULLETIN in 1953.

APPENDIX

DISCUSSION OF PAPER BY BABINGTON AND KLEPPINGER ON ALUMINUM DIE CASTINGS

Written discussions on the paper by W. Babington and D. H. Kleppinger on "Aluminum Die Castings—The Effect of Process Variables on Their Properties" which was appended to the 1951 Report of Committee B-6,[1] were received from Edward Jacobi of the Briggs and Stratton Corp. and J. Lapin of The Dow Chemical Co.

Mr. Edward Jacobi.[2]—This publication is probably the most valuable contribution to the art that has been published to the present time, by reason of its wealth of carefully determined numerical data. These data were established by a most thorough and painstaking investigation, scientifically conducted. No doubt, these results will be used for guiding die-casting process adjustments to get the best results. We have studied the data in our work for that purpose. They will also be used to check theories proposed in the future, to study the limiting conditions under which castings can be produced at all, or to be of optimum quality, and to calculate the fundamental physical properties of molten metals and the coefficients in formulas for injection flow and heat flow under practical die-casting conditions.

The table of conditions and results in Table I, shows some interesting relations. These may be found by study of the variations of results in strength or in the appearance quality and soundness of the product as a consequence of varying one casting condition while keeping all other conditions constant. For example, Figs. 21 and 22, which exhibit the effects of measured pressures on the mechanical properties indicate that variations in strength are not great over a wide range of pressures and other casting conditions. These figures show, though, that the strongest castings are obtained only within a much narrower range than the full range over which castings could be produced.

From Table I, it is notable that castings of good soundness rating and quality index are obtained generally at a narrow range of observed die face temperatures. Slight departures from the best temperature appear to result in large variations in quality and in strength.

TABLE I.—EFFECT OF GATE VELOCITY ON MEAN QUALITY.

Average V_p, ft per min	V_g, ft per sec	Gate Thickness, in.	Mean Quality Rating
127.1	21.6	0.090	5.53
126.8	64.4	0.030	6.88
388.0	65.5	0.090	6.21
365.8	186	0.030	7.52

The flow velocities of the gate would seem to be susceptible of the most accurate estimation by employing the plunger speed data measured by the drum type recorder. It is stated there that the speed at all points of the stroke may be obtained from these charts and that they were taken for approximately every tenth casting.

Assuming that the stream of metal

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 169 (1951).

[2] Chief Engineer, Briggs and Stratton Corp., Milwaukee, Wis.

between the plunger and the gate constriction is not broken, but fills the channels between those two points, the relative velocities should be inversely proportional to the cross-sectional areas of the plunger and of the gate. From the gate velocities determined by this method, the instantaneous pressure exerted upon the metal at any instant of the injection period should be determinable from the equation that connects the gate velocity, the area of the gate, and the actual pressure in the metal.

The velocities stated in the tables and charts appear to be the maxima in the individual strokes, averaged from the measured strokes under each set of conditions.

The pressure charts like Fig. 7 show an inclined rise and a gradual decline. The direction of time, on this chart, if known, could be related to the corresponding plunger speed record to isolate the portion of the pressure graph during the injection period. Examination of the original records in this manner would enable the establishing of the relation between pressure ahead of the plunger at the "biscuit" with the velocities of the plunger and in the gate.

The pressures stated in Table I presumably are the static pressures after the mold is filled and averaged for the castings made under each set of casting conditions. These pressures appear to correspond to the peaks of the strain measurements, Fig. 7.

The changes of slope of the plunger speed records, toward the end of the stroke, may give some significant indications of hydraulic friction and inertia effects in the hydraulic system of the die-casting machine.

The observations of the directions of flow during the filling period are valuable.

Possible Further Advancement in the Die Casting Art:

It appears to me that a complete science of die casting will require a theory of the relation of injection to the rate of heat abstraction. It may be that the injection factor will be expressed by velocity at the gate or by the speed of flow of streams of metal along the die wall as the mold is being filled, or by a combination of these velocities.

The solution of the problem of determining the most favorable combination of casting conditions depends on an equation of metal flow related to heat abstraction. The heat abstraction depends on the cyclical heat flow into and out of the die walls.

It may not be necessary, in view of the publication of this present monumental paper, to continue with a large program of experiments. Rather, it may be more fruitful to fit a mathematical theory to the available data plus additional data from investigations of other shapes and sizes of castings, and other ranges of casting conditions. Such further data might be obtained even from commercial casting operations without the need for large scale laboratory researches.

A team of scientists of various talents for the attack of this problem might include practical mathematical physicists experienced in solidification metallurgy, in rapid cyclical heat flows through branching paths, in hydrodynamics, and in the attainment of numerical results from equations that may not yield to classical methods of solution. This last implies resort to the use of a computing machine.

While this mode of attack could get started using present known fundamental physical properties as average values of coefficients in the calculations, more precise data may be found desirable. Thus measurements could be made of the physical properties of molten metal and the modifying effects of high pressures on these properties. The following list suggests some of the data that might be sought for various alloys, over ranges of temperatures and pressures:

- Specific heat,
- Density,
- Viscosity,
- Heat conductivity,
- Heat capacity,
- Heat conductivities of die steel of various alloys, and
- Heat conductivities of various surface film on various steels.

It seems to me that this work could be conducted gradually as individuals could be found with the necessary experience. Not all parts of the research need be attacked at once. The various parts could be performed as needed.

MR. J. LAPIN.[3]—The data presented in this report and the conclusions arrived at have a considerable practical value. However, the theoretical importance is marred by the lack of pressure data during the die-filling portion of the plunger stroker.

Since P_m was not determined, the calculation of gate velocity by the use of the Jacobi formula cannot be made. However, since accurate measurements were made of plunger velocity, V_g is determined readily by the relation, $V_g = \frac{A_p V_p}{A_g}$ assuming a full gate during the filling interval. This assumption and method of determining V_g was used in the Jacobi paper.[4] For the plunger velocity and gate thickness at which highest quality castings were produced, namely, 375 ft per min and 0.030 in. respectively, and using the 1$\frac{3}{4}$-in. diameter as reported to the writer by Mr. Kleppinger, $V_g = \frac{(0.0167)(6.25)}{0.0005479}$ or, 191 ft per sec.

From this it is evident that, in order to test the validity of the Jacobi formula, we need pressure charts which show metal pressures against position of the plunger. This pressure must then be integrated over the die filling portion of the stroke and the mean pressure used as P_m.

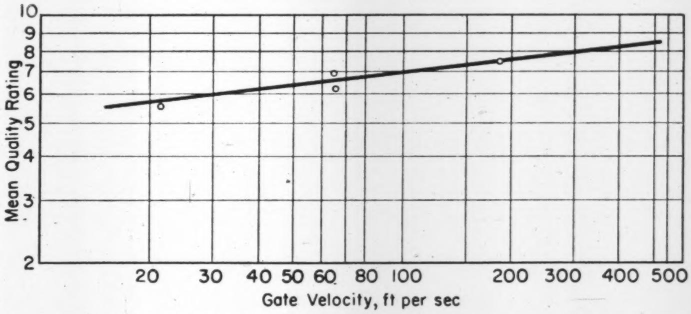

FIG. 1.—Effect of Gate Velocity on Mean Quality Rating-Aluminum Test Casting.

Such pressure charts should be obtained for a much wider range of gate geometry than used in this project. This will enable accurate predication of P_m when plunger velocity, gate size and shape are known, and thus contribute greatly to understanding the die-casting process. I recommend such a project to this committee.

The authors conclude that, included in optimum casting conditions are, a thin gate (0.030 in.), high plunger velocity (375 ft per min), and a gate velocity of

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[3] The Dow Chemical Co., Midland, Mich.

[4] E. Jacobi, "Flow Calculations for Die-Casting Applied to ASTM Committee B-6 Test Casting Die," ASTM BULLETIN, No. 166, May 1950, p. 65 (TP 127).

1090 ft per sec (which is actually 191 ft per sec as was just shown). A question which suggests itself is what would be the quality and soundness rating of castings made with the 0.090-in. gate if a gate velocity of 191 ft per sec were also used, corresponding to a plunger velocity of 1125 ft per min? A summary of quality ratings as against gate velocities abstracted from the data in Table I of the paper is presented in the accompanying Table I and shown graphically in Fig. 1. Only those runs were used in which the die was vented with the 0.010-in. shims.

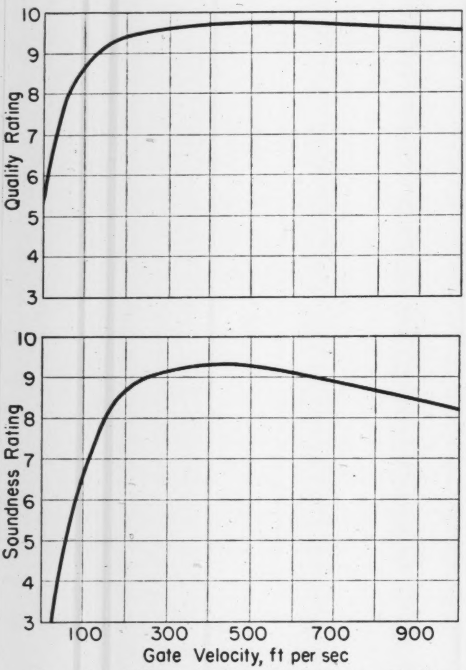

FIG. 2.—Effect of Gate Velocity on Quality and Soundness of Magnesium Die-Cast Test Panels.

It can be seen that mean quality rating varies not as a function of plunger velocity or gate thickness but in direct relation to gate velocity. The conclusion that high-quality castings may be obtained with a 0.090-in. thick gate if the gate velocity is high enough, namely, about 200 ft per sec or higher, seems to be reasonable. This question of whether quality is a function of gate velocity only or of gate velocity restricted to a thin gate may well be investigated much further.

In the case of magnesium die casting, some work was done in this direction a few years ago in our laboratory and some of the results are shown in Fig. 2. In this case gate thickness ranged from $\frac{1}{32}$ in. to $\frac{1}{16}$ in. and the test panel thickness was $\frac{1}{16}$ in. Somewhat similar results were obtained for a $\frac{1}{8}$ in. thick panel, where gate thickness ranged up to $\frac{1}{8}$ in. It is interesting to note that the lower limit of gate velocity for the highest quality and soundness range was found to be about 200 ft per sec, substantially the same gate velocity which was found to be optimum for aluminum by Messrs. Babington and Kleppinger. How much improvement could be made by going to even higher velocities should certainly be determined. For magnesium, our laboratory reported the upper limit to be about 500 ft per sec at which point soundness and quality began to fall off.

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT*

Committee B-7 on Light Metals and Alloys held two meetings during the year: one at Atlantic City, N. J., in June 1951 and one at Cleveland, Ohio, in March 1952.

During the year, 5 members were added to the committee. At the present time the committee consists of 81 members of whom 77 are voting members, 39 are classified as producers, 29 as consumers, and 13 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, I. V. Williams.
Vice-Chairman, Walter Bonsack.
Secretary, R. B. Smith.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revision of Standard Specifications for:

Magnesium Ingot and Stick for Remelting (B 92 – 45).

Revision of Tentative Specifications for:

Magnesium-Base Alloy Sand Castings (B 80 – 49 T),
Magnesium-Base Alloy Sheet (B 90 – 49 T),
Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 – 49 T),
Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 179 – 50 T), and
Magnesium-Base Alloy Permanent Mold Castings (B 199 – 49 T).

The revisions of Tentative Specifications B 93 – 49 T and B 179 – 50 T together with the tentative revision of Standard Specifications B 92 – 45 were accepted by the Standards Committee on September 12, 1951. The remainder of the recommendations were accepted on November 27, 1951. They all appear in the 1951 Supplement to Book of ASTM Standards, Part 2.

NEW TENTATIVES

The committee recommends for publication as tentative the following as set forth in the Appendix to this report:[1]

Tentative Recommended Practice for:

Codification of Light Metals and Alloys, Cast and Wrought.

Tentative Specifications for:

Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications,
Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications.

REVISION OF TENTATIVES

The committee recommends revisions in the following 10 tentative specifications as set forth in the Appendix to this report:

Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (B 26 – 50 T),

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 2.

Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 – 51 T),
Aluminum-Base Alloy Permanent Mold Castings (B 108 – 50 T),
Aluminum and Aluminum-Alloy Sheet and Plate for Use in Pressure Vessels (B 178 – 51 T),
Aluminum and Aluminum-Alloy Sheet and Plate (B 209 – 51 T),
Aluminum-Alloy Drawn Seamless Tubes (B 210 – 50 T),
Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 – 49 T),
Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 49 T),
Aluminum-Alloy Extruded Tubes (B 235 – 50 T), and
Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 – 48 T).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following five tentative specifications, which have stood for two years or more without revision, be continued as tentative:

Tentative Specifications for:

Magnesium-Base Alloy Forgings (B 91 – 49 T),
Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 49 T),
Magnesium-Base Alloy Extruded Round Tubes (B 217 – 49 T),
Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (B 234 – 50 T), and
Aluminum-Alloy Pipe (B 241 – 50 T).

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends that the Standard Specifications for Magnesium Ingot and Stick for Remelting (B 92 – 45)[2] be revised for immediate adoption to incorporate the tentative revisions[3] issued September 1951 and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

REAFFIRMATION OF STANDARDS

The committee recommends that the following four standards, which have stood for more than six years without revision, be reaffirmed:

Standard Specifications for:

Aluminum Ingots for Remelting (B 24 – 46).

Standard Method of Test for:

Dielectric Strength of Anodically Coated Aluminum (B 110 – 45),
Sealing of Anodically Coated Aluminum (B 136 – 45), and
Weight of Coating on Anodically Coated Aluminum (B 137 – 45).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3a]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Aluminum Alloy Castings (D. L. Colwell, chairman), in cooperation with the American Foundrymen's Society, prepared comprehensive tables evaluating the properties and characteristics of the casting alloys and recommends their incorporation in revisions of Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 50 T), and Aluminum-Base Alloy Permanent Mold Castings (B 108 – 50 T).

Subcommittee V on Testing Light Metals (R. L. Templin, chairman) has been investigating statistical sampling methods as applied to testing for mechanical properties but does not recommend their inclusion in specifications under the jurisdiction of the committee. The investigation is being continued.

Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys (J. D. Edwards, chairman) was inactive during the past year but plans to prepare specifications for anodic coatings on aluminum during the coming year.

Subcommittee VII on Codification of Light Alloys (R. B. Smith, chairman) prepared a new Tentative Recommended

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[2] 1949 Book of ASTM Standards, Part 2.

[3] 1951 Supplement to Book of ASTM Standards, Part 2, p. 345.

[3a] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Practice for Codification of Light Metals and Alloys, Cast and Wrought, which was presented to the Society through the Administrative Committee on Standards. It was not accepted and was returned for further consideration. The part pertaining to codification of tempers has been deleted and the revised Recommended Practice is recommended for publication as a new tentative. Further work on codification of tempers is in progress.

Subcommittee VIII on Atmospheric Exposure Tests (L. H. Adam, chairman) has obtained test specimens of 30 aluminum and 8 magnesium alloys and has been active in having them installed at four Society atmospheric exposure test sites: on top of the Port of Authority Building, New York City, for industrial atmospheric conditions; State College, Pa., for rural; Kure Beach, N. C., for Atlantic Coast marine; and Point Reyes, Calif., for Pacific Coast marine. The New York and State College specimens have been installed. The Kure Beach specimens are waiting for installation of insulators on the metal mounting frames. The Point Reyes site is not ready for the specimens.

This report has been submitted to a letter ballot of the committee, which consists of 81 members; 53 members returned their ballots, of whom 52 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

I. V. WILLIAMS,
Chairman.

R. B. SMITH,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering light metals and alloys which are referred to earlier in this report. The standards appear in their present form in the 1949 Book of ASTM Standards, Part 2; the 1950 Supplement to Book of ASTM Standards, Part 2; or the 1951 Supplement to Book of ASTM Standards, Part 2.

REVISIONS OF TENTATIVE SPECIFICATIONS

The committee recommends that the following 10 tentative specifications be revised as indicated below and continued as tentative.

Specifications for Aluminum-Alloy Sand Castings (B 26 – 50 T):[4]

Appendix.—Revise to read as follows: The data in the following Tables IV and V are approximate and are supplied for general information only."

Table IV.—Retain Table IV, *Typical Yield Strengths* without change.

New Table.—Add a new Table V titled *Properties and Characteristics* to read as shown in the accompanying Table I.

Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 – 51 T):[3]

Table I.—Add a zinc limit of 0.20 per cent maximum for alloy AM100A to make the ingot suitable for castings conforming to B 80 – 51 T and B 199 – 51 T which have a zinc limit of 0.3 per cent maximum.

Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 50 T):[4]

Appendix.—Revise to read as follows:

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[4] 1950 Supplement to Book of ASTM Standards, Part 2.

"The data in the following Tables IV and V are approximate and are supplied for general information only."

Table IV.—Retain Table IV, *Typical Yield Strengths* without change.

TABLE I.—PROPERTIES AND CHARACTERISTICS.

Alloy	Pattern Shrinkage Allowance in./ft.[m]	Approx. Melting Range, F[o]	Foundry Characteristics					Other Characteristics								
			Resistance to Hot Cracking[a]	Pressure Tightness	Fluidity[b]	Solidification Shrinkage Tendency[c]	Normally Heat Treated	Resistance to Corrosion[d]	Machining[e]	Polishing[f]	Electroplating[g]	Anodizing (Appearance)[h]	Chemical Oxide Coating (Protection)[i]	Strength at Elevated Temp.[j]	Suitability for Welding[k]	Suitable for Brazing[l]
C4A	5/32	970 to 1190	4	4	3	3	Yes	3	2	2	1	2	3	3	3	No
CG100A	5/32	965 to 1155	3	3	3	3	Yes	4	1	2	1	3	4	1	4	No
CN42A	5/32	990 to 1175	4	3	3	4	Yes	4	2	2	1	3	4	1	4	No
CS43A	5/32	970 to 1160	2	2	2	2	No	4	3	3	2	3	3	3	2	No
CS72A	5/32	965 to 1160	3	3	2	3	No	5	2	2	2	3	4	3	3	No
G4A	5/32	1110 to 1185	4	5	5	5	No	1	1	1	5	1	1	2	4	No
G10A	1/10	840 to 1120	2	5	4	5	Yes	1	1	1	4	1	1	(n)	5	No
GS42A	5/32	1090 to 1170	3	4	3	4	No	1	2	2	4	2	1	3	4	No
S5A	5/32	1065 to 1170	1	1	1	1	No	2	5	5	2	5	2	4	1	Ltd.
S5B	5/32	1065 to 1170	1	1	1	1	No	3	5	5	2	5	2	4	1	Ltd.
SC51A	5/32	1015 to 1150	1	1	1	1	Yes	3	3	3	1	4	2	2	2	No
SC64B	5/32	950 to 1125	2	2	2	2	Yes	3	3	4	2	4	3	3	2	No
SC64C	5/32	960 to 1120	2	2	2	2	Yes	3	3	4	2	4	3	3	2	No
SC82A	5/32	960 to 1135	1	1	1	1	Yes	3	4	5	2	4	2	2	2	No
SG70A	5/32	1035 to 1135	1	1	1	1	Yes	2	4	5	2	4	2	3	2	No
ZC81A	3/16	...	5	3	4	4	Aged Only	2	1	1	2	2	3	5	4	Yes
ZG32A	3/16	1030 to 1175	5	3	4	4	Aged Only	2	1	1	3	2	2	5	4	Yes
ZG42A	3/16	1020 to 1170	5	3	4	4	Yes	2	1	1	3	2	2	5	4	Yes
ZG61A	3/16	...	5	3	4	4	Aged Only	2	1	1	2	2	3	5	4	Yes
ZG61B	3/16	1105 to 1195	5	3	4	4	Aged Only	2	1	1	2	2	3	5	4	Yes

NOTE.—1 indicates best of group, 5 indicates poorest of group.

[a] Ability of alloy to withstand contraction stresses while cooling through hot-short or brittle temperature range.

[b] Ability of liquid alloy to flow readily in mold and fill thin sections.

[c] Decrease in volume accompanying freezing of alloy and measure of amount of compensating feed metal required in form of risers.

[d] Based on alloy resistance in standard type salt spray test.

[e] Composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. Ratings, in the case of heat-treatable alloys, based on —T6 temper. Other tempers, particularly the annealed temper, may have lower rating.

[f] Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure.

[g] Ability of casting to take and hold an electroplate applied by present standard methods.

[h] Rated on lightness of color, brightness and uniformity of clear anodized coating applied in sulphuric acid electrolyte.

[i] Rated on combined resistance of coating and base alloy to corrosion.

[j] Rating based on tensile and yield strengths at temperatures up to 500 F, after prolonged heating at testing temperature.

[k] Based on ability of material to be fusion-welded with filler rod of same alloy.

[l] Refers to suitability of alloy to withstand brazing temperatures without excessive distortion or melting.

[m] Allowances for average castings. Shrinkage requirements will vary with intricacy of design and dimensions.

[n] Not recommended for service at elevated temperatures.

[o] Temperatures of solidus and liquidus are indicated, pouring temperatures will be higher.

New Table.—Add a new Table V titled *Properties and Characteristics* to read as shown in the accompanying Table II.

Specifications for Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 – 51 T).

These specifications were completely revised and appear in revised form in the 1952 Book of ASTM Standards, Part 2.

Specifications for Aluminum and Aluminum - Alloy Sheet and Plate (B 209 – 51 T):[4]

Table I.—Add a titanium limit of 0.15 per cent maximum for the core of alloy Clad CS41A.

Table II.[5]—For alloy MG11A, F temper, correct thickness range to read "0.250 to 3.000" instead of "0.250 to 0.300." Change requirements for alloy G1A to increase the size ranges as shown in the accompanying Table III.

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[5] All footnotes in Table II are lettered the same as in B 209 – 50 T. However, the 1951 revision deletes Footnote *b* and reletters subsequent footnotes accordingly.

For alloy GS11A, O temper, delete yield strength requirement for thicknesses greater than 0.500 in. by revising as shown in accompanying Table IV.

In Note *e* add "Plate heat treated by the purchaser shall show a minimum yield strength of 38 000 psi, and its correct temper designation is T 42".

In Note *f* change the fourth word "material" to "sheet", and add "Plate heat treated by the purchaser shall show a minimum yield strength of 38 000 psi, and its correct temper designation is T 42".

TABLE II.—PROPERTIES AND CHARACTERISTICS

Alloy	Approximate Melting Range, F[m]	Foundry Characteristics: Resistance to Hot Cracking[a]	Pressure Tightness	Fluidity[b]	Solidification Shrinkage Tendency[c]	Normally Heat Treated	Other Characteristics: Resistance to Corrosion[d]	Machining[e]	Polishing[f]	Electroplating[g]	Anodizing (Appearance)[h]	Chemical Oxide Coating (Protection)[i]	Strength at Elevated Temp.[j]	Suitability for Welding[k]	Suitable for Brazing[l]
CG100A	965 to 1155	4	4	3	4	Yes	5	1	2	1	3	4	1	4	No
CN42A	990 to 1175	4	4	3	4	Yes	4	2	2	1	2	3	1	4	No
CS42A	970 to 1170	4	3	3	3	Yes	4	3	2	1	3	2	2	4	No
CS66A	930 to 1110	2	3	3	3	Yes	5	3	2	2	4	3	2	4	No
CS72A	965 to 1160	3	3	2	3	No	5	2	2	2	3	4	3	4	No
CS104A	945 to 1110	2	3	2	3	No	5	2	2	5	4	5	2	3	No
GS42A	1090 to 1170	3	4	4	4	No	1	1	1	5	2	1	3	5	No
GZ42A	1075 to 1180	4	5	5	4	No	1	1	1	4	1	1	3	5	No
S5A	1065 to 1170	1	1	1	2	No	2	5	4	2	4	2	4	1	Ltd.
S5B	1065 to 1170	1	1	1	2	No	3	5	4	2	4	2	4	1	Ltd.
SC51A	1015 to 1150	1	1	2	2	Yes	3	3	3	2	4	2	2	2	No
SC64A	970 to 1135	2	2	2	2	No	4	3	3	2	3	3	3	2	No
SC64B	950 to 1125	2	2	2	3	Yes	3	3	3	2	4	3	3	2	No
SC64C	960 to 1120	2	2	2	3	Yes	3	3	3	2	4	3	3	2	No
SC122A	980 to 1060	1	2	1	3	Yes	3	4	5	3	5	2	2	2	No
SG70A	1035 to 1135	1	1	2	1	Yes	2	3	3	1	4	2	3	2	No
SN122A	1000 to 1050	1	2	1	3	Yes	3	4	5	4	5	2	2	2	No
ZC60A	1120 to 1190	5	4	4	5	Aged Only	2	1	1	2	1	2	5	4	Yes
ZC81B	...	5	4	4	5	Aged Only	2	1	1	2	1	2	5	4	Yes
ZG32A	1030 to 1175	5	4	4	5	Aged Only	2	1	1	3	1	2	5	4	Yes
ZG42A	1020 to 1170	5	4	4	5	Yes	2	1	1	3	1	2	5	4	Yes

NOTE.—1 indicates best of group; 5 indicates poorest of group.

[a] Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature range.

[b] Ability of liquid alloy to flow readily in mold and fill thin sections.

[c] Decrease in volume accompanying freezing of alloy and measure of amount of compensating feed metal required in form of risers.

[d] Based on resistance of alloy in standard type salt spray test.

[e] Composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. Ratings, in the case of heat-treatable alloys, based on —T6 temper. Other tempers, particularly the annealed temper, may have lower rating.

[f] Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure.

[g] Ability of casting to take and hold an electroplate applied by present standard methods.

[h] Rated on lightness of color, brightness and uniformity of clear anodized coating applied in sulphuric acid electrolyte.

[i] Rated on combined resistance of coating and base alloy to corrosion.

[j] Rating based on tensile and yield strengths at temperatures up to 500 F, after prolonged heating at testing temperature.

[k] Based on ability of material to be fusion-welded with filler rod of same alloy.

[l] Refers to suitability of alloy to withstand brazing temperatures without excessive distortion or melting.

[m] Temperatures of solidus and liquidus are indicated, pouring temperatures will be higher.

Specifications for Aluminum - Alloy Drawn Seamless Tubes (B 210 - 50 T):[4]

Table I.—Add alloy G1A, with chemical requirements as shown in accompanying Table V.

Table II.—Add alloy G1A, with tensile requirements as shown in the accompanying Table VI.

Table III.—Add alloy G1A in headings of Columns 2 and 3.

Table IV.—Add alloy G1A in heading of Column 3.

TABLE III.

Temper	Thickness, in.	Tensile Strength, psi.	Yield Strength, min., psi.[a]	Elongation in 2 in., min., per cent	Bend Diameter Factor, N
		ALLOY G1A			
O	0.009 to 0.019	24 000 max	..	16	0[c]
	0.020 to 0.031	24 000 max	..	18	0[c]
	0.032 to 0.113	24 000 max	..	20	0[c]
	0.114 to 0.249	24 000 max	..	22	0[c]
	0.250 to 1.000	24 000 max	..	20	2
H32	0.013 to 0.050	22 000 min	..	4	1
	0.051 to 0.249	22 000 min	..	6	2
H34	0.009 to 0.031	25 000 min	..	3	1
	0.032 to 0.050	25 000 min	..	4	1
	0.051 to 0.161	25 000 min	..	5	2
	0.162 to 0.249	25 000 min	..	5	3
H36	0.009 to 0.019	27 000 min	..	2	3
	0.020 to 0.050	27 000 min	..	3	3
	0.051 to 0.161	27 000 min	..	4	4
H38	0.009 to 0.031	29 000 min	..	2	[d]
	0.032 to 0.050	29 000 min	..	3	[d]
	0.051 to 0.113	29 000 min	..	4	[d]
F	0.016 to 1.000	[i]	..	[d]	[d]

Specifications for Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 – 49 T):[2]

Table I.—Add a titanium limit of 0.15 per cent maximum for alloy CS41A.

Specifications for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 49 T):[2]

Table I.—Add a titanium limit of 0.15 per cent maximum for alloy CS41A.

Specifications for Aluminum-Alloy Extruded Tubes (B 235 – 50 T):[4]

Table I.—Add a titanium limit of 0.15 per cent maximum for alloy CS41A.

Specifications for Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 – 48 T).

These specifications were completely revised and appear in revised form in the 1952 Book of ASTM Standards, Part 2.

TABLE IV.

Temper	Thickness, in.	Tensile Strength, psi	Yield Strength min, psi.[a]	Elongation in 2 in., min, per cent	Bend Diameter Factor, N
O	0.010 to 0.020	22 000 max	12 000 max	14	...
	0.021 to 0.128	22 000 max	12 000 max	16	...
	0.129 to 0.500	22 000 max	12 000 max	18	...
	0.501 to 1.000	22 000 max	...	18	...
	1.001 to 3.000	22 000 max	...	16	...

TABLE V.

Alloy[b]	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Manganese, per cent	Magnesium, per cent	Zinc, per cent	Chromium, per cent	Titanium, per cent	Other Elements, per cent	
										Each	Total
G1A	remainder	0.25	0.80	0.50	0.15	1.0 to 1.8	0.25	0.10	....	0.05	0.15

TABLE VI.

Alloy	Temper	Wall Thickness, in.	Tensile Strength, psi.	Yield Strength,[a] min., psi.	Elongation in 2 in. or 4 × Diam., min., per cent	
					Full-Section Specimens	Cut-Out Specimens
G1A	O	0.010 to 0.500	24 000 max	....	..	..
	H34	0.010 to 0.500	25 000 min	....	..	..
	H38	0.010 to 0.500	29 000 min	....	..	..

REPORT OF COMMITTEE B-8

ON

ELECTRODEPOSITED METALLIC COATINGS*

Committee B-8 held two meetings during the year: one on November 8, 1951 at ASTM Headquarters in Philadelphia, Pa., and one in Cleveland, Ohio, on March 7, 1952.

The membership of the committee now consists of 00 members, of whom 00 are classified as producer, 00 as consumer, 0 as general interest, and 0 as consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. H. Sample.

Vice-Chairman, K. M. Huston.

Secretary, R. B. Saltonstall.

Advisory Committee Members-at-large, H. E. Head and G. A. Lux.

The American Electroplaters' Society has officially endorsed ASTM specifications and recommended practices B 200, B 201, B 177, B 252, B 253, and B 254. Other tentatives and standards under the jurisdiction of B-8 have been endorsed previously, or are the result of a joint effort. A mechanism has been established to facilitate A.E.S. endorsement of future tentatives produced by Committee B-8.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is making editorial revisions in nine tentatives and standards to give coating thickness values in microns as well as decimal inches.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications, Papers, and Definitions (J. E. Stareck, chairman).—*Section A* (W. P. Barrows, chairman) has reviewed Specifications A 166 - 45 T, B 142 - 45 T and B 200 - 45 T, correcting certain inconsistencies and recommending revisions suggested by new information. This report is being circulated to the subcommittee for letter ballot and comment.

Section B (G. Soderberg, chairman) has been appointed to cooperate with parallel efforts of the Editorial Board of the American Electroplaters' Society and other interested organizations to create a glossary of terms used in plating, polishing, and allied operations.

Section C (K. M. Huston, chairman) has submitted to Subcommittee I a Suggested Format for Recommended Practices for the Preparation of Materials for Electroplating, in the interest of uniformity of present and future practices. This is being circulated to the subcommittee for comment.

Steps have been taken to increase the activity of Subcommittee I in reviewing proposed Federal Specifications pertaining to electroplating.

Subcommittee II on Performance Tests (W. L. Pinner, chairman).—Four working sections have been appointed.

Section A (B. B. Davis, chairman) has the responsibility for the copper-nickel-chromium exposure tests, present and future. Because of incongruities in exposure data on the panels exposed in 1947 and 1951, additional panels are being prepared for exposure.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

Section B (A. H. DuRose, chairman) has the responsibility for the lead-coated steel exposure tests, and has reported that previously noted trends are continuing. More panels have been removed for determination of loss in weights of lead and steel, as well as loss in tensile strength.

Section C (J. E. Stareck, chairman) will have the responsibility for exposure and inspection of zinc- and cadmium-plated panels, on which the deposits have been given supplemental treatments. These panels are currently being prepared by Subcommittee V of Committee B-8.

Section D (Carl Durbin, chairman) has been formed to review and otherwise study for purposes of revision, the present methods now used in rate exposed test panels. Particular attention will be given to placing proper emphasis on various defects as they relate to the true protective value of the coatings. Cleaning some of the panels in each set at regular intervals by a standard procedure will also be considered.

Subcommittee III on Conformance Tests (B. C. Case, chairman).—*Section A* on thickness tests has nearly completed its task of evaluating the reproducibility of various thickness test methods. The statistical analysis of the data remains to be completed.

Section B on porosity has distributed the panels indented by the Olsen Cup Method and then nickel plated, to four cooperating laboratories for salt fog testing, and some data has been obtained. When complete, the data will be analyzed statistically.

Section C on hardness and adhesion has diminished in membership, but new interest was evidenced and it is expected that the partially completed work on panels for hardness measurement will be accelerated.

Section D on brightness and luster has a new chairman, G. B. Bowman, and work is proceeding satisfactorily on the difficult task of measuring these properties of electrodeposited coatings.

Subcommittee IV on Electroplating Practice (Max Frager, chairman).—One new tentative recommended practice for the preparation of copper and copper-base alloys for electroplating has been cleared and is ready for letter ballot of the main committee.

Section F on plating on plastics has been reorganized under a new chairman, William Neill, and is working on a recommended practice.

Section G (G. Herrmann, chairman) has been formed to prepare a recommended practice for the preparation of lead and alloys for electroplating.

Section J (J. H. Lansing, chairman) has been formed to prepare a recommended practice for the preparation of malleable and gray iron for electroplating.

Subcommittee V on Supplemental Treatments for Metallic Coatings (Marc Darrin, chairman).—*Section B* on accelerated tests reports that the preparation of several hundred test panels at the National Bureau of Standards is progressing satisfactorily.

Section C on performance is cooperating with Section C of Subcommittee II in planning exposure tests on the panels being prepared by Section B. Outdoor exposure at two sites and boxed exposure in an unheated warehouse are contemplated.

Section D on supplemental treatments for cadmium has more than half completed a comprehensive program involving about 900 panels. Variations in chromate treatment, the effect of periodic reverse plating, plated specimens coupled with copper, brass, aluminum, magnesium, and stainless steel, and some massive panels to evaluate condensation effects are all included in this study.

Section E on phosphate treatments is making good progress in its evaluation of the effectiveness of phosphate treatments for protection against corrosion and for surface preparation for subsequently applied finishes.

Section F on supplemental organic finishes over zinc and chromium plate has been reorganized with a new chairman, F. L. Scott, and accelerated activity is anticipated.

This report has been submitted to letter ballot of the committee, which consists of 111 voting members; 73 members returned their ballots, of whom 52 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. H. SAMPLE,
Chairman.

R. B. SALTONSTALL,
Secretary.

REPORT OF COMMITTEE B-9
ON
METAL POWDERS AND METAL POWDER PRODUCTS*

This report covers the activities of Committee B-9 on Metal Powders and Metal Powder Products for the period from June, 1951, to June, 1952. During this time, one meeting was held in Cleveland, Ohio, on March 5, 1952.

This being an even numbered year, officers were elected to serve until the Annual Meeting in the Spring of 1954. These officers were W. A. Reich, Chairman, D. S. Urquhart, Vice-Chairman, F. V. Lenel, Secretary; and J. R. Boettler, C. G. Johnson, K. H. Roll, and G. L. Werley, members of the Advisory Committee.

NEW TENTATIVE

The committee recommends to the Society the publication as tentative of the attached proposed Tentative Recommended Practice for Evaluating the Microstructure of Apparent Porosity in Cemented Carbides.[1] This proposed tentative has been submitted to letter ballot of the committee and the results will be announced at the Annual Meeting of the Society.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Sintered Metal Powder Structural Parts (B 222 – 50 T)[2] be adopted as standard by the Society. This recommendation has been submitted to letter ballot of the committee, and the results will be announced at the Annual Meeting.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Definitions of Terms Used in Powder Metallurgy (B 243 – 49 T)[2] be retained as tentative in view of several pending additions and modifications.

ADVISORY COMMITTEE ACTIVITIES

The advisory Committee had three meetings during the year to act on various committee administrative matters. Particular attention was devoted to the planning of the Symposium on Methods of Testing Metal Powders and Metal Powder Products, which was held on March 4 during the Spring Meeting of the Society in Cleveland. This Symposium was well received and the papers presented are being compiled into a monograph to be published by the Society. Further efforts were extended to increase the consumer representation on Committee B-9.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Technical Data (F. N. Rhines, chairman) had one meeting during the year. Several terms were considered for inclusion in the glossary (B 243 – 49 T), notable among which was the noun "Sinterings" to describe products made by sintering metal powders. Technical data sheets are being prepared on material covered by Specifications B 222 – 50 T mentioned previously. A procedure for torsion testing of sintered material was presented by Roy Blue and is under consideration by the subcommittee.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 2.

[2] 1949 Book of ASTM Standards, Part 2.

Subcommittee II on Metal Powders (J. J. Cordiano, chairman) is balloting on four tentative methods for chemical analysis of metal powders mentioned in last year's report, and if approved the methods will be submitted to Committee E-3 for further action.

Similar action is under way on a proposed tentative method for subsieve analysis of granular metal powders by air classification, which, after subcommittee ballot, will be voted on by the main committee.

The proposed tentative method for compressibility testing of metal powders is the subject of a cooperative program of testing. These tests will include copper and iron powders, and will involve the use of various dies by individual cooperators as well as the use of the same die by various participants.

Subcommittee III on Metal Powder Products (R. P. Koehring, chairman):

Section A on Bearings (D. S. Urquhart, chairman) held two meetings during the year. A tentative size list to be appended to the Tentative Specifications for Metal Powder Sintered Bearings (Oil Impregnated) (B 202 – 51 T) has been drawn up. Minor modifications remain to be made before submitting this list to section ballot.

Section B on Structural Parts (C. G. Johnson, chairman) held two meetings during the year. The proposed tentative specification for brass structural parts has been modified as a result of questions raised during the first letter ballot. It will shortly be resubmitted to the section for ballot. Progress was made in the drafting of proposed specifications for copper-impregnated structural parts and porous filters made from metal powders.

Section C on Sintered Carbides (J. C. Redmond, chairman) has devoted its major effort during the year to developing standard procedures for testing cemented carbides. The attached proposed Tentative Recommended Practice for Evaluating the Microstructure of Apparent Porosity in Cemented Carbides[1] was mentioned previously. The cooperative program on hardness testing was successful in that good agreement was obtained between cooperating laboratories, and a proposed tentative method for this determination is being drafted. A survey of various methods of density determination was made by H. W. Highriter and it will be the subject of an ASTM BULLETIN article. A proposed tentative method for this determination using the balance method is also being drafted.

This report has been submitted to letter ballot of the committee, which consists of 56 members; 36 returned their ballots, of whom 33 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. A. REICH,
Chairman.

F. V. LENEL,
Secretary.

REPORT OF
ADVISORY COMMITTEE ON CORROSION[1]

A billion dollars is a conservative estimate of the loss each year due to the corrosion of metals. The effects of atmospheric deterioration on plastics, rubber, textiles, wood, and other engineering materials would more than double this figure.

The American Society for Testing Materials has long recognized the tremendous economic significance of these problems, and has been one of the foremost contributors to knowledge in these fields by conducting authoritative and impartial atmospheric and other exposure tests that have provided engineers with reliable data for design and operation of structures and equipment of all kinds. This article, after briefly reviewing the Society's accomplishments in a period of some 40 years, presents plans for placing ASTM Exposure Testing on a firm, long-time basis to assure a continued flow of authentic data on deterioration characteristics of a wide variety of materials ranging from the various ferrous and non-ferrous metals and their alloys through paints, ceramics, rubber, adhesives, plastics, textiles, wood, and "composite" constructions.

Exposure Tests

The Society's work on atmospheric exposure tests dates back more than 40 years to the formation of the committees now designated as Committee D-1 on Paint, Varnish, Lacquer, and Related Products and Committee A-5 on Corrosion of Iron and Steel. In 1906 the first-named committee started the now classic tests of paints on the Pennsylvania Railroad Bridge at Havre de Grace, and shortly thereafter the second committee began exposure tests at Pittsburgh of twelve samples of galvanized wire with different weights of coatings. Since these early beginnings the Society, through the activities of seven of its committees, now has more than 20,000 test specimens on exposure at 17 outdoor test sites and expects the number of specimens to double within the next few years. A brief account of this work follows, including references to some major contributions to engineering knowledge that have resulted and mention of plans for future work.

Committee A-5 on Corrosion of Iron and Steel

Earlier Work:

Committee A-5, one of the oldest committees in the Society actively engaged in corrosion research, was organized in 1906 as Committee U. The first report of the committee was published in 1907, while the 1908 report outlined more clearly the various problems before the committee.

In 1909 the committee reported data from twelve samples of galvanized wire with different coatings exposed at Pittsburgh. An interim report on these tests was given in 1910 (the committee then had its present designation A-5) and a complete report on the same tests in 1911. In the meantime the committee, in cooperation with Committee

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[1] This report supplements the first "Report of Advisory Committee on Corrosion," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 211 (1947).

D-1, reported in 1910 the results of tests on painted steel fence panels erected in 1908 at Atlantic City.

Copper-Bearing and Non-Copper-Bearing Uncoated Sheets.—In 1915 the committee took preliminary steps for testing the effect of steel composition by exposure tests at Fort Sheridan, Ill., Pittsburgh, Pa., and Annapolis, Md. Analyses of the sheets used were given in the 1916 and the 1918 reports and actual exposure was started in 1916–1917. Cumulative reports on the tests at all three locations were given in 1918, 1920, 1921, 1922, and 1923 when the Pittsburgh tests were completed. Reports on the two remaining locations continued in 1924, 1925, 1926, 1927, and 1928, when data on the Fort Sheridan tests were presented in detail, as these tests had to be concluded because the space used was no longer available. The 1946 report of the committee gives cumulative results of the tests at all three test sites. The Annapolis reports have continued biennially to date with the latest report presented in 1952. The No. 22 gage tests were concluded in 1952 after 35.5 yr.

Zinc-Coated Sheets.—In 1917 and 1919 the committee published reports on preservative metallic coatings for metals which discussed methods of testing zinc coatings.

Atmospheric Corrosion Tests—New Series:

In 1920 the committee recognized the desirability of undertaking a very extensive corrosion test program and plans for these tests materialized during the next few years while the funds necessary for carrying them out were obtained by special subscription. The tests, as finally organized, were divided into three distinct groups and reports on progress to date are listed below.

Uncoated and Galvanized Corrugated Sheets.—Committee A-5 began studies in 1926 at five test locations (Altoona, Pa.; Brunot Island, Pittsburgh, Pa.; Sandy Hook, N. J.; State College, Pa.; Key West, Fla.) representing various atmospheric conditions, on corrugated sheets, both uncoated and galvanized with various weights of zinc coating. A report of failures of all galvanized sheets after 7-yr exposure at Altoona and of progress at other sites was published in 1934, and failure of all sheets after $8\frac{1}{2}$-yr exposure at Pittsburgh in 1935. A brief report of correlation of results of the Brunot Island tests on sheets, hardware, and structural shapes and electroplated coatings on steel was included in the 1936 report.

In 1938 initial failures observed at State College were reported; a comparison was made of the relative severity of the five locations on coated and uncoated sheets; the behavior of coated sheets at five test locations was described. The 1944 report recorded (*a*) coating failures at Sandy Hook and State College, (*b*) the behavior of coatings at Key West in detail, (*c*) deterioration of ten uncoated sheets exposed at five test locations to show contribution of coatings to life of sheets, and (*d*) data on elapsed time between exposure and perforation. Loss of weight experiments at Sandy Hook to show seasonal variations in corrosivity started April, 1939. Interesting details of this test and further data on specimens at State College and Key West were reported in 1942. Later data on the galvanized sheet exposure tests were included in the 1946, 1948, 1950, and 1952 reports.

Due to an unfortunate error in 1951 by the Corps of Engineers, a large number of the heavier gage sheets at Sandy Hook were lost, and it was agreed to discontinue the sheet tests at this location.

The test site at Brunot Island (Pittsburgh, Pa.) was discontinued in the spring of 1951, as the area occupied was needed for plant expansion by the owners. It also was found necessary to relocate the Key West site in 1949 and again in 1952. Sheet tests were discontinued at Brunot Island in 1951, and the final inspection of the Key West sheets was made early in 1952. Final data for these three sites appear in the 1952 report of Committee A-5.

Metallic-Coated Hardware, Structural Shapes, Tubular Goods, etc.—In 1928

Committee A-5 began studies at the same five test locations noted above, on metal products coated by commercial operations with the following eight types of coatings: hot-dipped zinc, electrodeposited zinc, sherardized (zinc) applied in gas-heated drum, sherardized (zinc) applied in electrically-heated drum, electrodeposited cadmium, hot-dipped aluminum, hot-dipped lead (Amaloy), parkerized. Diagrams showing the rack mountings of the various specimens were given in the 1929 report. Results of inspections of the specimens at all test locations after 2-, 4-, and 6-yr exposures were reported in 1931, 1933, and 1935, respectively. In 1936 a brief report was given on correlation of results of this project with other corrosion studies by the committee. In 1938 extensive data were given showing rusting that had occurred on samples since the 1935 report.

Later the hardware racks at State College and Sandy Hook were reconditioned with numerous specimens remounted—largely those with hot-dipped zinc, aluminum, or lead coatings and some sherardized coatings, and the 1943 report showed the identification and positioning on the racks of the remounted samples as well as the positions on the original racks. A full report on the progress to date was included in the 1944 *Proceedings*, where it was noted that the series of tests at Pittsburgh and Altoona were involuntarily concluded due to loss of all specimens in 1939 and 1942, respectively. The Key West specimens were relocated (in Key West) in 1949 and again in 1952 due to changes in test site location made necessary by expanding Naval facilities. Data on results at the three remaining locations were given in the 1946, 1948, 1950, and 1952 reports. The Sandy Hook tests were discontinued in 1952. Additional hardware tests are now being planned (1952) which will duplicate some of the early tests and will include most of the coatings produced commercially today.

Wire and Wire Products.—Extensive country-wide outdoor tests of wire, and wire products, including unfabricated wire, barbed wire, wire strand, farm field fencing and chain link fence as outlined in the 1934 report were started in 1936 at 11 test locations (Sandy Hook, N. J.; Bridgeport, Conn.; State College, Pa.; Lafayette, Ind.; Ames, Iowa; Manhattan, Kans.; Ithaca, N. Y.; Santa Cruz, Calif.; College Station, Tex.; Davis, Calif.; Brunot Island, Pittsburgh, Pa.). Materials include uncoated wire and fencing (both copper-bearing and non-copper-bearing), zinc-coated wire and fencing, corrosion-resisting steel wire and fencing, lead-coated wire and fencing, and copper-coated wire and fencing.

The 1937 committee report provided detailed data on the installation of test materials. In the 1939 report there were given the results of 2-yr exposure tests at all locations and detailed data of referee tests at the National Bureau of Standards which provided complete information on original characteristics of the materials on test, including photomicrographs, etc.

At each location, there were more than 900 specimens, including short lengths of wire and wire strand at all eleven locations, farm field fence at nine sites, and barbed wire and chain link fence at eight test sites.

When the Brunot Island site was discontinued in 1951, the remaining wire specimens were transferred to the roof of the Bureau of Mines in Pittsburgh and subsequently in 1952 to a warehouse roof of Williams and Co., Pennsylvania and Galveston Aves. As many wire specimens as possible were salvaged in 1952 after the damage to the Sandy Hook site and the tests at this location were terminated. Complete reports of the wire tests are included in the A-5 reports in the odd-numbered years. The 1951 report summarized the 14-yr data including the 1950 inspections.

Electrodeposited Coatings.—A special subcommittee, working jointly with the American Electroplaters' Society and the National Bureau of Standards, was organized in 1931 to study corrosion of electrodeposited coatings. Test specimens were exposed in 1932 at six locations. Data were reported in 1933, 1934 and 1936. (See also Research Paper No. 867 of the National Bureau of Standards (*Journal of Research*, Vol. 16, No. 2, 1936).) In 1941 this work was transferred to the newly formed Committee B-8 on Electrodeposited Metallic Coatings.

Other Tests:

Total Immersion Tests.—Total immersion tests of No. 16 and No. 22 gage ferrous sheets in mine water at Calumet, Pa., tap water at Washington, D. C., and river water at Annapolis, Md., were started by Subcommittee V in 1920. These test materials were the same as those used in 1916 atmospheric exposure tests. Results at Calumet, Pa., were reported in detail in the 1921 A-5 report and data on the same tests in tap water at the National Bureau of Standards and in Severn River water at Annapolis were given in 1924. Further progress reports were given yearly. The final data from the No. 22 gage sheets were included in the 1926 report and from the No. 16 gage sheets in the 1930 report of A-5.

In 1926 total immersion tests were started on 2-in. steel pipe and on riveted steel plates using iron and steel rivets. Test locations were Portsmouth, N. H., Key West, Fla., and Port Arthur, Tex. In 1927 samples cut from the same sheets used for the 1920 tests were exposed at Portsmouth and Key West. The No. 22 gage samples were reported as completely failed in 1932 (Portsmouth) and 1933 (Key West). Complete data on sea water sheet failures were given in 1940. Progress reports on the pipe specimens and riveted plates were made yearly (with the exception of 1938 and 1939) until the pipe tests were concluded in 1939. The tests on the riveted specimens were discontinued in 1940 when the Port Arthur, Tex., specimens were reported lost.

The final report of Subcommittee V was published in 1950.

Sulfuric Acid Tests.—Tests started in 1930, and reported in detail in 1931 were undertaken to determine if correlation could be established between the 20 per cent sulfuric acid test (the pros and cons of which had been argued since the committee was formed in 1906) and the results obtained on the same types of material in long-time atmospheric corrosion testing. The committee found that the sulfuric acid test was not capable of consistent repetition nor of correlation with service and that data from such tests should not be used to forecast the relative life of ordinary ferrous materials in the atmosphere.

Embrittlement Test.—Work on embrittlement testing started in 1931 with an extended discussion and bibliography of the subject. A recommended practice for the embrittlement test (A 143) was published in 1932.

Specifications and Methods of Test:

Extensive studies involving tests for determining weight and uniformity of zinc coatings on hardware and other shapes, and tests for plated coatings including metallographic, stripping, dropping, spot tests, etc., resulted in various standards covering the following: weight of coating (A 90), uniformity of coating (A 239), thickness of electrodeposited coatings (A 219), and weight and composition of coating on long terne sheets (A 309).

A special group issued a report (March, 1942, BULLETIN) on the demand for, and relative merits of, methods for the dropping test to determine thickness of zinc and cadmium coatings on steel. Some consideration was also given by this group to magnetic test methods for determining the thickness of coatings.

Thirteen specifications for zinc coatings (galvanizing) of various iron and steel products and articles have been developed by the committee. These include sheet (A 93), line wire (A 111, A 326), tie wire (A 112), farm fencing (A 116), chain link fence (A 117, A 337), barbed wire (A 121), wire strand (A 122, A 218), structural shapes (A 123) hardware (A 153), terne sheets (A

308), and roofing sheets (A 361). Other specifications, including electrodeposited coatings of zinc (A 164), cadmium (A 165), and lead (A 267), have been written.

COMMITTEE A-10 ON IRON-CHROMIUM, IRON-CHROMIUM-NICKEL, AND RELATED ALLOYS

As noted later in this report under Committee B-4, the Symposium on Corrosion-Resistant, Heat-Resistant and Electrical-Resistant Alloys sponsored by Committee B-2 in 1924 led indirectly to the establishment of Committee A-10 in 1929. Attached to this symposium in the 1924 *Proceedings* was an extensive tabulation of the properties of corrosion-resistant and heat-resistant alloys. Responsibility for this tabulation was taken over by Committee A-10 and a greatly enlarged presentation of data was published by Committee A-10 in the 1930 *Proceedings*. Subsequently, additional information was added from time to time and the information was published separately in 1942. The 1942 information covered wrought steels only and was combined in 1950 with data on cast steels as *STP No. 52-A*, "Data on Corrosion- and Heat-Resistant Steels and Alloys—Wrought and Cast."

The corrosion work of Committee A-10 began with its organization in 1929 under the direction of its Subcommittee on Methods of Corrosion Testing, which published its first report in 1933. This report included analyses of salt-spray testing, copper sulfate stain testing, and boiling nitric acid testing.

In 1938 a subcommittee was appointed to examine architectural installations of stainless steel, and in 1939 its first report was published appended to the committee report.

Supplementary reports on Inspection of Stainless Steel Structures were published in 1940, 1948, and 1949. Also in 1940 the committee began working with Committee B-3 on studies of atmospheric galvanic corrosion of stainless steel in contact with non-ferrous metals and alloys.

The first of several methods of test developed by Committee A-10 was the Recommended Practice for Conducting Plant Corrosion Tests (A 224) which was published in 1939. This was revised in cooperation with Committee B-3 in 1946 to make the method applicable also to non-ferrous metals. In 1941 work was begun on a general procedure for testing in boiling liquids, resulting in 1942 in a Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262). A Method of Total Immersion Testing of Stainless Steels (A 279) was published in 1944. In addition to these methods of test, Committee A-10 has developed specifications for many stainless steel products including: plate, sheet, and strip (A 167, A 176, A 177, A 240), tubing (A 268, A 269, A 270, A 271), cladding (A 263, A 264, A 265), bars (A 276), castings (A 296, A 297), pipe (A 312), spring wire (A 313), billets and bars for reforging (A 314) and centrifugal castings (A 362). Last year (1951) Emergency Alternate (EA) provisions were added to A-10 specifications containing columbium-bearing grades of stainless steels to permit the use of columbium-tantalum alloys.

The committee also prepared for Frankford Arsenal a summary on the Passivation of Stainless Steels. This summary, as well as data on the performance of corrosion-resisting steel on the deck houses of two Navy destroyers, was appended to the 1946 committee report.

Considerable activity in recent years has centered about the work of Subcommittee V on Metallography and its work on identification of sigma phase and the relation of this phase to physical properties.

The subcommittee also has completed details of a plan for a new 15-yr exposure test of corrosion-resisting steels and is currently endeavoring to procure the thousands of test specimens necessary under the program.

COMMITTEE B-3 ON CORROSION OF NON-FERROUS METALS AND ALLOYS

Committee B-3 was organized in 1922 for the purpose of improving the technique of corrosion testing in the field of non-ferrous metals, of standardizing it in so far as possible, and later of assembling standard data on the corrosion resistance of different non-ferrous metals and alloys.

Standard Corrosion Procedures:

As the first project of the committee, cooperative corrosion tests were conducted at 14 laboratories on a series of companion samples of 6 non-ferrous metals, by 4 methods—simple immersion, alternate immersion, spray, and accelerated electrolytic. Six solutions were used in each case, 2 acids, 2 alkalies, 2 neutral solutions. The correlated results, published in 1927, have served as background for the further development of these corrosion test procedures except the electrolytic test which was abandoned.

Plans maturing over a period of several years for the study of corrosion of non-ferrous metals under different conditions of service culminated in 1931 in the starting of three series of tests. These included long-time outdoor exposure tests; corrosion in liquids (manufacturers' plant conditions); and galvanic corrosion of coupled metals under outdoor exposure conditions.

This work culminated in the adoption by the Society of procedures for total immersion corrosion test (B 185); alternate immersion corrosion test (B 192); and salt spray corrosion (fog) test (B 117). Committees A-5 and D-1 cooperated in developing B 117.

Salt Spray:

The salt spray test has continued to be extensively used by industry, and a subcommittee is now engaged in determining the factors essential in this test method. Consideration is also being given to the use of a combined acetic acid-salt spray particularly in connection with the evaluation of plated coatings on die castings.

Outdoor Exposure Tests:

At nine widely separated sites in various parts of the United States (State College, Pa.; Phoenix, Ariz.; Pittsburgh, Pa.; Altoona, Pa.; Rochester, N. Y.; New York City, N. Y.; Sandy Hook, N. J.; Key West, Fla.; La Jolla, Calif.), exposure tests of projected 20-to 25-yr duration were started in 1931 on 24 representative non-ferrous metals and alloys. The sites were typical of heavy industrial, light industrial, rural, seacoastal, and inland dry atmospheres. Specimens were of two types; precut tension test specimens and 9- by 12-in. sheets (see 1932 report). These were to be used for measuring the corrosion rate by progressive change in tensile properties and also by loss of weight and change in surface characteristics. Samples were withdrawn at intervals for testing.

The first phase of the work (10-yr period) was finished in 1941, the results were published in the committee's reports for 1943 and 1944. The second phase of the long-time outdoor exposure tests was completed and the specimens removed in 1951, with the exception of the La Jolla specimens which were recalled in 1950 when this test site had to be discontinued.

Corrosion in Liquids:

This series of tests in a number of common chemical solutions was planned to be representative of corrosion conditions in manufacturers' plants. Many of the materials in these tests were identical with those of outdoor exposure tests. Because of the unsettled industrial conditions during the depression, the progress of this series was disturbed considerably. However, the tests were completed and the results published in 1934, 1935, and 1938.

Galvanic Corrosion:

In the first series of tests the materials used were the same as those of the outdoor exposure tests and typical two-metal couples were exposed in 1931 at the same test sites. The final report was published in 1939. Supplementing this series another series was started in 1941 with stainless steel specimens (types 304 and 316) coupled to eight selected non-ferrous metals and to mild steel. Three of the exposure sites of the previous series (New York City, State College, and Altoona) were utilized, together with a new one at Kure Beach, N. C. (see 1942 report). The first set of specimens was removed in 1946 at the end of 5-yr exposure, tested for contact resistance, disassembled, visually inspected, weight changes determined, and the resultant data reported in 1948. The remaining couples will be left on exposure until 1956.

A third series of galvanic couple tests consists of two types of magnesium alloys coupled to other metals and alloys. This is a three-part program. (See 1946 report of Committee B-3 for details.) Exposure of the first part, consisting of disk-type specimens, was begun at New York, N. Y., and Kure Beach, N. C., in the latter part of 1949 and at Miraflores, C. Z., and State College, Pa., early in 1950.

Spool type specimens of Part II of the program have been on exposure since 1951 and it is hoped that the plate-type specimens for Part III will be ready within a year.

Weather:

A subcommittee was formed (1942) to study the various elements which make up "weather" and to attempt a "more precise evaluation of those weather factors which influence atmospheric corrosion and a correlation of such factors with the performance of materials under test." The ultimate aim would be to extend the basis for the intelligent application of results of the atmospheric exposure tests, particularly in respect to their use in estimating performance of materials at locations other than those at which large-scale tests are made. (See 1943, 1946, and 1947 reports.) An evaluation of the relative corrosivity of various locations was begun in 1948 with the exposure of mild steel and rolled zinc specimens at Sandy Hook, N. J., State College, Pa., Pittsburgh (Brunot Island) Pa., Kure Beach, N. C., Vandergrift, Pa., Kearny, N. J., Middletown, Ohio, and New York City, N. Y. Exposure of calibration specimens at Point Reyes, Calif., was begun in 1952. Removal of specimens was scheduled for 1-, 2-, 4-, and 8-yr intervals.

Other Activities:

In 1946 suggested changes were adopted which made the Recommended Practice for Conducting Plant Corrosion Tests (A 224), developed originally for corrosion-resisting alloys, applicable to the testing of non-ferrous metals.

The Subcommittee on Statistical Analysis and Planning of Corrosion Testing will continue to aid other subcommittees in planning tests so that data obtained may be treated statistically.

COMMITTEE B-4 ON ELECTRICAL HEATING, RESISTANCE, AND RELATED ALLOYS

The Symposium on Corrosion-Resistant, Heat-Resistant and Electrical-Resistant Alloys, suggested by Committee B-2 on Non-Ferrous Metals in 1924, led directly to the establishment of Committee B-4 in the following year (and indirectly, on the recommendation of a joint committee of representatives of Committees A-5 and B-3 in 1928, to the establishment of Committee A-10 in 1929).

The interest of Committee B-4 in corrosion testing has been primarily in the field of high-temperature service and in 1929 the committee sponsored the Method of Accelerated Life Test for Metallic Materials for Electrical Heating (B 76). In 1937 a Subcommittee on Methods of Test for Alloys in Controlled Atmospheres was organized to study the effect of furnace atmospheres on resistors and evolve a method of test. This resulted in the publication in 1943 of a Method of Test for the Effect of Controlled Atmospheres Upon Alloys in Electric Furnaces (B 181). Work on similar tests on castings used in furnaces began in 1942 and still continues, using samples of nickel oxide and chromium trioxide under various furnace atmospheres together with pieces of 80 Ni - 20 Cr furnace ribbon, to study the causes and prevention of "green rot" in electric furnaces using controlled atmospheres. A study of thermocouple protection tubes and their penetration by hydrogen has also been initiated.

Considerable effort has been devoted to the study of the effects of humidity on wire life at high temperatures. Recent investigations (1950) have indicated the use of silicon in high-temperature alloys to be beneficial. Work is continuing on the effect of sulfur in these resistance types of alloys.

COMMITTEE B-6 ON DIE-CAST METALS AND ALLOYS

Before Committee B-6 was organized in 1930, work in the die-casting field was carried on by Subcommittee XV of Committee B-2. This subcommittee began its work in 1928, and in 1929 started atmospheric exposure tests of about 35,000 test specimens of 22 different zinc-base and aluminum-base die casting alloys secured from eight producers. Outdoor exposure locations were at State College, Pa.; Key West, Fla.; Sandy Hook, N. J.; Rochester, N. Y.; Altoona Pa.; and New York City, N. Y. Indoor exposure test locations were at Coco Solo, Panama Canal Zone; Hanover, N. Mex.; New Kensington, Pa.; and Cambridge, Mass. The 1929 report of Committee B-2 gave a statistical basis for analysis of the test results. A picture of one of the outdoor exposure test racks was shown in the 1930 report of Committee B-2. Committee B-6 was organized in June, 1930, and subsequent data on the exposure tests are to be found in its reports.

The report in 1932 on 1-yr exposure tests at all locations except State College showed the definite superiority of Alloy XXI to the other experimental zinc-base alloys, especially as indicated by the retention of impact strength.

In 1935 the report of the committee gave the detailed results of the 5-yr exposure results on twelve aluminum and ten zinc-base alloys, while the 1940 report gives further information on the 5-yr test as well as the physical properties and the expansion data after 10-yr atmospheric exposure.

A series of tests on two aluminum-base alloys was started in 1943. These tests included corrosion resistance to 20 per cent salt spray at 95 C and atmospheric exposure at New York, N. Y., and Sandy Hook, N. J. Results were appended to the 1948 report.

Also in 1948, earlier tests at the Key West site were relocated (in Key West) due to sale of the test site area by the Navy to the city. The specimens were transferred to the Fort Taylor area. It was found necessary to change the Key West test site location also in 1949 and again in 1952.

In 1945 the committee reported that all of the zinc- and aluminum-base alloy test bars exposed in 1929 and the 5-yr test bars of zinc and magnesium alloys (1939 series) had been recalled. The same ten locations were used for the 1939 series except that Phoenix, Ariz., was substituted for Hanover, N. Mex. In the 5-yr interval between 1939 and 1944 the Rochester specimens disappeared, hence data are available only from nine locations. Also in 1945 two test specimens of special purity aluminum and one standard aluminum alloy exposed in 1935 at three outdoor locations (Sandy Hook, New York and Altoona) were recalled for examination. Data on these three tests were appended to the 1946 report.

The 10-yr data for the magnesium- and zinc-base alloys (1939 series) were reported in 1950. The remaining specimens from this series will be left on exposure until 1959 (20 yr).

The committee's reports on its various tests have been quite complete and some pertinent data have been added each year; in addition to those years which have been mentioned, see particularly 1934, 1937, and 1939.

The results of these exposure tests were directly responsible for the development or revision of several B-7 specifications. The die-casting specifications developed by Committee B-7 include aluminum (B 85), zinc (B 86), magnesium (B 94), lead and tin (B 102), copper-base (brass) (B 176), and zinc-base alloys in ingot form (B 240).

The committee has also sponsored a number of papers on the subject of the die-casting alloys. Among these are the papers on "The Effect of Variations in Aluminum Content on the Strength and Permanence of ASTM No. XXIII Zinc Die-Casting Alloy" by Anderson and Werley, appended to the 1934 report; papers by Fox on "Finishing of Die Castings" (1936), by Werley on "A Study of Die Design Changes for the Improvement of the Soundness and Uniformity of Test Bars" (1947), by Winston on "Magnesium Alloy Die Castings" (1949), by Kelton on "Fatigue Testing of Zinc-Base Alloy Die Castings" (1942), and by Babington and Klepinger on "Aluminum Die Castings—The Effect of Process Variables on Their Properties" (1951).

COMMITTEE B-7 ON LIGHT METALS AND ALLOYS, CAST AND WROUGHT

Tests of Aluminum and Aluminum Alloys:

Committee B-7 organized in 1928 established a Subcommittee on Anodic Oxidation of Aluminum and Aluminum Alloys in 1936 to study (*a*) thickness, (*b*) abrasion resistance, and (*c*) electrical breakdown voltage, of anodic coatings on aluminum. A discussion of the problem was given in an appendix to the 1937 report. In 1940, four papers dealing with various phases of the problem were presented by Keller; Edwards; Arlt; and by Compton and Mendizza. The work of the committee has resulted in the publication of three test methods for anodized aluminum as follows: dielectric strength (B 110), scaling (B 136), weight of coating (B 137), and thickness (B 244). Appended to the 1943 and 1945 reports are interesting comparisons of the performance of anodic coatings on wrought aluminum alloys when exposed to the salt spray test and to the weather. Atmospheric exposures (started in 1941) were made at Philadelphia, Pa.; Chicago, Ill.; New Kensington, Pa.; Miami, Fla.; Point Judith, R. I.; Oakland, Calif.; and New York City, N. Y. The results generally speaking, indicated that while salt spray exposure tests may disclose coatings subject to early failure, the resistance of most anodic coatings to this type of exposure is sufficiently extended so that the method could scarcely be considered an accelerated test.

Tests of Magnesium and Aluminum Alloys:

The committee prepared preliminary plans several years ago for a test to determine the corrosion behavior of the standard cast and wrought magnesium alloys but was prevented by the war from carrying out the program. Subsequent to the war, the plans for a magnesium alloy test program were abandoned in favor of a more extensive investigation of both aluminum and magnesium alloys.

Exposure of these specimens was begun at State College, Pa., New York City, N. Y., and Kure Beach, N. C., early this year (1952). It is expected that the remainder of the specimens will be mounted within a few months.

COMMITTEE B-8 ON ELECTRODEPOSITED METALLIC COATINGS

Corrosion work in Committee B-8 started shortly after the organization of the committee in 1941, with the committee investigation of current practices of salt spray corrosion testing of electrodeposited coatings.

Completed work of the committee consists of the summation and application of completed intersociety exposure tests in a series of specifications for electrodeposited coatings; and Subcommittee III's report (1943) on Salt Spray Corrosion Testing. Partially as a result of the latter, further ASTM effort has been directed toward improving the procedure of salt spray corrosion testing. This has finally resulted in the much improved Method B 117.

Lead Coatings:

Outdoor atmospheric exposure tests of various electrodeposited lead coatings on steel were started in 1944 and a supplementary series in 1950. The exposure sites for these tests are New York City, N. Y.; State College, Pa.; Kure Beach, N. C.; and Tela, Honduras. The test was described in detail in the 1944 report and results of exposure data were given in the committee's reports for 1946, 1947, 1949, and 1951.

Copper-Nickel-Chromium Coatings:

Atmospheric exposure specimens of copper-nickel-chromium coatings on high-carbon steel of bumper bar grade were started in 1946 and 1950. Test panels were exposed at New York, N. Y.; Pittsburgh, Pa.; State College Pa.; and Kure Beach, N. C. The purpose of the test was to determine the optimum ratio of copper to nickel in composite coatings of copper-nickel-chromium on high-carbon steel. Results of exploratory tests were reported in 1947 and interim data in 1949 and 1951.

The copper-nickel-chromium coatings exposed in 1950 included platings on rolled nickel as well as high-carbon steel. In addition the copper undercoating was varied on part of the high-carbon steel specimens.

Future Tests:

It is planned to make studies of the effect of abrasive grain size used in polishing the base metal on the protective value of the electrodeposited coatings. Some work along these lines has already been done on steel by the American Electroplaters' Society, using ASTM racks for the exposure tests. Some of the work on steel will probably be repeated and the program expanded to include other base metals such as zinc and brass.

A study of the mechanism of corrosion through discontinuities in electrodeposited coatings will also be made. In this connection the committee hopes to promote fundamental studies of the problem, obtain data for the construction of polarization curves, observe and measure galvanic effects, etc.

It is also planned to develop and standardize accelerated corrosion tests for electrodeposited coatings which will be more suitable than those presently available. This would include studies of porosity testing methods with the view toward preparing recommended practices for the porosity testing of specific base metal-coating combinations.

A subcommittee which is concerned with supplementary treatments has made an exploratory study of chromate-treated zinc and cadmium finishes and plans have been formulated for a more extensive program to investigate five types of chromate treatments which will include the exposure of treated specimens to (*a*) industrial atmosphere, (*b*) marine atmosphere, (*c*) warehouse storage, (*d*) 100 per cent humidity, (*e*) pressure cooker, (*f*) salt spray (fog), and (*g*) water immersion.

A complementary program is being developed in which steel panels, zinc-plated, phosphate-treated, and coated with a clear alkyd varnish, will be subjected to various accelerated tests as well as atmospheric exposure. Variables will be acid and cyanide zinc, and thickness of phosphate coating.

COMMITTEE C-19 ON STRUCTURAL SANDWICH CONSTRUCTIONS

Committee C-19 was organized in 1948 and the following year requested and was granted representation on the Advisory Committee on Corrosion. A section on Exposure Facilities was established to assist the work of other sections by selecting and arranging for test sites and study is currently under way to develop exposure test procedures and to design an outdoor exposure test cubicle.

COMMITTEE D-1 ON PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS

Committee D-1 was organized in 1902 as Committee E on Preservative Coatings for Iron and Steel and early considered field service and laboratory testing. Various subcommittees were organized immediately, and in 1906 an extensive test of paints on the Pennsylvania Railroad Bridge at Havre de Grace was started. The inspection methods for these tests were outlined in the 1907 report, and an analysis of the paints used was given in the 1908 report. Detailed reports on the results of the Havre de Grace tests were published in 1910, 1911, 1913, 1914, and 1915.. In the meantime wooden panel tests had been started in Atlantic City in 1909 and reported on in 1910. An exposure test of steel panels made in cooperation with Committee A-5 was reported in 1911 and again in 1913, 1914, and 1915.

In 1916 a subcommittee was organized to study the preparation of iron and steel surfaces for painting. Test panels were prepared and exposed at Altoona and Brooklyn in 1917. Detailed reports of these tests were given in the 1918, 1919, 1921, 1923, 1924, 1925, 1926, and 1928 reports of the committee.

A study of chemical pretreatment of various steels, with subsequent painting and exposure, was started in 1939, reported on in some detail in 1941, and the first program of tests was completed in 1944.

White paints were exposed for test at Arlington, Va., in 1912 and reported on in detail in 1914. Tests of antifouling paints were started in 1921 at Norfolk, Va.; Raritan, N. J.; and Charleston, S. C.; and reported in detail in 1922, 1923, 1924, and 1925. Results of exposure tests on varnish were also reported in 1923. In 1940 the committee published a report on the Comparison of Accelerated Weathering *Versus* Outdoor Exposure for Paints, and further comparisons were contained in the 1942 report.

Paint Standards:

Committee D-1 cooperated with Committees A-5 and B-3 in the development of the method for Salt Spray Testing (B 117), and the results of the committee's work have resulted in the development of a number of specifications and methods of test, among which the following are typical:

Specifications for Wood to Be Used as Panels in Weathering Tests of Paints and Varnishes (D 358),

Method of Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products (D 609),

Method of Evaluating Degree of Resistance to Rusting Obtained with Paint on Iron or Steel Surfaces (D 610),

Method for Evaluating Resistance to Blistering of Paints on Metal When Subjected to Immersion or Other Exposure to Moisture or Liquids (D 714),

Methods of Evaluating Degree of Resistance to Flaking (Scaling) of Exterior Paints of the Linseed-Oil Type (D 722),

Method of Water Immersion Test of Organic Coatings on Steel (D 870),

Recommended Practice for Conducting Exterior Exposure Tests of Paints on Wood (D 1006),

Method of Conducting Exterior Exposure Tests of Paints on Steel (D 1014),

Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (D 1150),

Specifications for Asphalt-Base Emulsions for Use as Protective Coatings for Metal (D 1187), and

Recommended Practice for Characteristics of Standard Carbon Arc Accelerated Weathering Unit (E 42).

Current Activities:

Current activities consist of further study of several methods of chemical pretreatment of steels, followed by painting and exposure; correlation of operating procedures and rating methods for light and water exposure units;

development of methods for humidity test, with and without condensation; study of methods for preparation of steel and non-ferrous metal surfaces for painting; corrosion tests on steel structures in various locations (including evaluation of several methods of cleaning) to study the effect of variations in climate; and development of photographic standards to be representative of various conditions of ferrous surfaces prior to painting.

Painted wooden and metal panels to evaluate dirt retention were exposed in 1949. Wooden panels were exposed at Miami and Ormond Beach, Fla.; Kure Beach, N. C.; State College, Pa.; Chicago, Ill.; New York City, N. Y.; and Columbus, Ohio. Metal panels were exposed at the same sites with the exception of Miami. Both sets of tests will be terminated this year (1952).

COMMITTEE D-14 ON SCREEN-WIRE CLOTH

While Committee D-14 (organized in 1920, discharged in 1938) on Screen-Wire Cloth is no longer a functioning committee of the Society, during the course of its existence it conducted some very important atmospheric exposure tests. The first report of the committee was made in 1921 and in 1923 it presented to the Society a specification on screen-wire cloth (B 50). This specification was advanced to standard in 1929, but withdrawn when the committee was discharged in 1938.

In 1925 the committee started atmospheric exposure tests on seven non-ferrous screen cloth alloys of the following nominal compositions: (1) 90 per cent copper - 10 per cent zinc, (2) 80 per cent copper - 20 per cent zinc, (3) 75 per cent copper - 20 per cent nickel - 5 per cent zinc, (4) 70 per cent nickel - 30 per cent copper, (5) 100 per cent copper, (6) 98 per cent copper - 2 per cent tin and, and (7) 95 per cent copper - 5 per cent aluminum. The atmospheric exposure tests were made at Portsmouth, Va.; Pittsburgh, Pa. (Bureau of Mines roof); Balboa Heights, C. Z.; and at the National Bureau of Standards, Washington, D. C. Interim data were reported in 1926, 1927, and 1929. Appended to the 1926 report were results of tension tests and laboratory salt spray and alternate immersion tests.

In 1930 there was a report on the exposure tests up to 1929 with a summary of supplementary laboratory tests. A final report of the atmospheric exposure tests was made in 1935.

COMMITTEE D-14 ON ADHESIVES

Committee D-14, organized in 1944, sponsored in 1946 its first standard relating to the permanence of adhesives, Recommended Practice for Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives (D 904). This was followed by Recommended Practice for Determining the Effect of Moisture and Temperature on Adhesive Bonds (D 1151), Method of Test for Effect of Bacterial Contamination on Permanence of Adhesive Preparations and Adhesive Bonds (D 1174) and in 1951, Methods of Test for Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183).

Current work includes studies of the correlation between laboratory accelerated tests, including cyclic and continuous exposure to moisture and temperature, and the corrosion resistance of adhesives.

COMMITTEE D-19 ON INDUSTRIAL WATER

ASTM interest in the work of the Joint Research Committee on Boiler Feed Water Studies led to the formation of Committee D-19, organized in 1932 as Committee D-19 on Water for Industrial Uses. The present title was approved in 1948. This same year, 1948, marked the establishment of a Subcommittee on Water-Borne Industrial Wastes. The committee, working with the Joint Research Committee, has studied various phases of water corrosion, particularly those relating to embrittlement, and this has led to the publication of Method of Corrosivity Test of Industrial Water (USBM Embrittlement Detector Method) (D 807).

The embrittlement tester in this method is a design worked out by the committee, a previously suggested type having been described in a paper in 1938 by Straub and Bradbury, "A Method of Embrittlement Testing of Boiler Waters." Numerous other papers on corrosion testing of water have been published under the sponsorship of Committee D-19 including a paper by Schroeder, Berk, and Partridge in 1936 and one by Tajc in 1937.

Another phase of corrosion study in Committee D-19 has been in connection with the work of the National District Heating Association. A paper by J. H. Walker on the NDHA method of measuring corrosion was published in the 1940 *Proceedings* as part of a Symposium on Water. A Method of Corrosivity Test of Industrial Water (NDHA Method) (D 935) was completed in 1947. The Handbook on Corrosion of the Electrochemical Society contains a chapter on Boiler Corrosion written by the chairman and three other members of Committee D-19 and submitted on behalf of the committee. A Manual on Industrial Waters is currently being prepared by the committee.

In addition to D 807 and D 935 previously mentioned, Committee D-19 has developed a number of other standards relating to corrosion and corrosion products. These are:

Method of Field Sampling of Water-Formed Deposits (D 887),

Methods of Test for Dissolved Oxygen in Industrial Water (D 888),

Method of Reporting Results of Examination and Analysis of Water-Formed Deposits (D 933),

Method for Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction (D 934),

Methods of Test for Sulfate-Reducing Bacteria in Industrial Water and Water-Formed Deposits (D 993),

Methods of Test for Acidity and Alkalinity in Industrial Water (D 1067),

Method of Test for Electrical Conductivity of Industrial Water (D 1125),

Method of Identification of Types of Microorganisms in Industrial Water (D 1128),

Specification for Substitute Ocean Water (D 1141), and

Specification for Reagent Water (D 1193).

OTHER COMMITTEES

Other committees now becoming interested in exposure testing to determine deterioration characteristics of materials include Committees A-3 on Cast Iron, D-7 on Wood, and D-20 on Plastics.

ASTM BIBLIOGRAPHY

Many individual papers, relating to corrosion and weathering, in addition to numerous symposiums and topical discussions, have been sponsored by the various technical committees of the Society. Individual papers, not sponsored by a committee or appended to a committee report, have been published in the *Proceedings* or ASTM BULLETIN. A few symposiums have been sponsored jointly. Rather than to list these papers and symposiums (papers presented as a part of a symposium are not listed individually) with the work of the separate committees, a complete Bibliography of ASTM papers and publications from 1898 through 1951 is appended to this report as Appendix I.

ADMINISTRATION

The administration of these programs of exposure tests has posed an increasingly difficult problem. Nearly all of the tests so far, as will be evident from the foregoing presentation, are in the field of metals (that is corrosion), involving a half-dozen committees who at first were reasonably well able to coordinate their work through interlocking membership and by direct cooperation on specific projects of mutual interest. But, as time went on, four of these committees had acquired a total of 22 test sites, most being used jointly, but some exclusively by one committee, having different tenures of occupancy and conditions of use, and overlapping considerably in kind of prevailing atmospheric conditions. Efficient servicing of so many scattered sites was next to impossible through our voluntary committee organization.

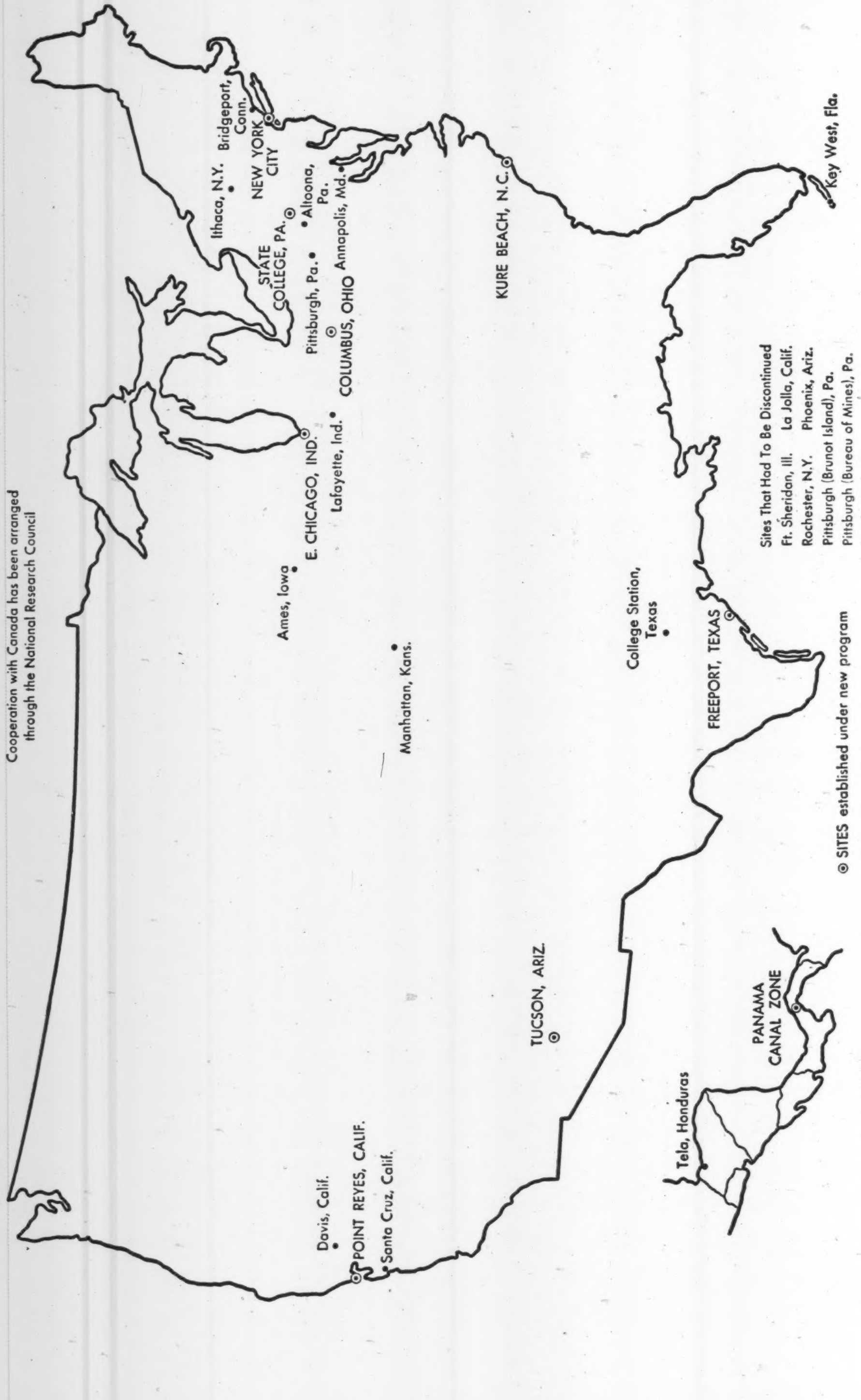
About ten years ago it became clear that tighter coordination was essential, and the Society in 1942 organized the Advisory Committee on Corrosion, primarily to coordinate all corrosion researches by metals committees of the Society and to consider simplification of the exposure test situation. The committee consists of "members-at-large" appointed by the Board of Directors and, initially, two representatives from those technical committees engaged in *corrosion* studies. As committees in the field of nonmetals seriously considered atmospheric exposure tests, for which test sites under the control of the Society are well suited, representation on the Advisory Committee was extended to *include other than metals committees* until at the present time the following committees are represented on the ACC:

A-3 on Cast Iron
A-5 on Corrosion of Iron and Steel
A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys
B-3 on Corrosion of Non-Ferrous Metals and Alloys
B-4 on Electrical-Heating, Resistance, and Related Alloys
B-6 on Die-Cast Metals and Alloys
B-7 on Light Metals and Alloys, Cast and Wrought
B-8 on Electrodeposited Metallic Coatings
C-19 on Structural Sandwich Constructions
D-1 on Paint, Varnish, Lacquer, and Related Products
D-14 on Adhesives
D-19 on Industrial Water

The Advisory Committee's study of the exposure test site problem was taken up actively at the end of the war. It soon became clear that far too many test sites were being operated and that a much smaller number could be selected that would represent collectively all of the types of atmosphere in which exposure tests were being made. Instances developed where a test site had become too small with no room for expansion; other sites had to be abandoned because of industrial encroachment; and still other sites had to be abandoned and tests interrupted because the space had to be reclaimed by the owner. Accordingly the Advisory Committee has paid particular attention to long and secure tenure of occupancy, adequate size, and as much freedom as possible from later encroachment. The Board of Directors has given to the Advisory Committee on Corrosion responsibility for the acquisition and maintenance of ASTM exposure test sites and jurisdiction in all matters having to do with the use of the test sites.

NEW TEST SITES SELECTED

The Advisory Committee on Corrosion has selected nine test sites representative of various types of atmosphere, large enough to provide for all seeable future needs, and of long tenure of occupancy so far as such can be assured in advance. These are briefly described and are spotted on the accompanying map, which also shows other test sites that are now in use but probably will be discontinued when tests there are completed. It will be seen that an important addition to the classes of sites already in operation are those in the Canal Zone where both mild and severe tropical atmospheres exist. The possibility also of use, in cooperation with the National Research Council of Canada, of sites where extreme low temperatures prevail is a most interesting one and completes the wide range of atmospheric conditions available for ASTM exposure testing.


Cooperation with Canada has been arranged through the National Research Council
Bridgeport, Conn.
Ithaca, N.Y.
NEW YORK CITY
STATE COLLEGE, PA.
Altoona, Pa.
Annapolis, Md.
Pittsburgh, Pa.
COLUMBUS, OHIO
KURE BEACH, N.C.
Key West, Fla.
E. CHICAGO, IND.
Lafayette, Ind.
Ames, Iowa
Manhattan, Kans.
College Station, Texas
FREEPORT, TEXAS
TUCSON, ARIZ.
Davis, Calif.
POINT REYES, CALIF.
Santa Cruz, Calif.
PANAMA CANAL ZONE
Tela, Honduras
Sites That Had To Be Discontinued
Ft. Sheridan, Ill.
La Jolla, Calif.
Rochester, N.Y.
Phoenix, Ariz.
Pittsburgh (Brunot Island), Pa.
Pittsburgh (Bureau of Mines), Pa.
Sandy Hook, N.J.
⊙ SITES established under new program
• Other sites now in use

Industrial Atmosphere:

New York City, N. Y.—Arrangements have been made with the Port of New York Authority for the use of an area of about 20,000 sq ft on the roof of the 16-story Authority Building at Eighth Ave. and Fifteenth St. in New York City. The atmosphere is typically industrial and similar to those of Pittsburgh and Altoona where exposure tests have been conducted in the past. Five 57½-ft pipe frames capable of holding 3500 4- by 6-in. specimens have already been installed on the Port Authority roof and a number of tests are in progress involving more than 2000 specimens.

East Chicago, Ind.—The Christiansen Corp. has made available to the Society an acre of ground in East Chicago, Ind. This site also is typically industrial in nature and was established primarily as a result of discussions concerning the possible "marine contamination" of the New York site. Construction of pipe frames has been completed in anticipation of contemplated exposure programs involving this location.

Semi-Industrial Atmosphere:

Columbus, Ohio.—Arrangements have been completed with Battelle Memorial Institute for the use of a penthouse section on the roof of a five-story Institute building in Columbus. The area presently available is about 11,000 sq ft; other roof areas are available at the Institute if needed later. There are a number of railroad shops approximately two miles southeast and the prevailing winds are from this direction. Battelle tests indicate that this is a typical atmosphere intermediate between industrial and rural. Facilities are available for exposure of 700 4- by 6-in. specimens.

Rural Atmosphere:

State College, Pa.—The long-established test site at Pennsylvania State College, first used by the Society in 1925, furnishes a typical rural atmosphere as borne out by tests extending over the past quarter century. An area of more than 30,000 sq ft is currently available and thousands of tests are on exposure at this site.

Tucson, Ariz.—Although definite arrangements have not yet been completed there seems reasonable assurance that tentative negotiations now under way will result in the establishment of a test site in the Tucson area within the next few months. This location is representative of the hot, dry, rural atmosphere typical of the southwestern part of the United States.

Marine Atmosphere:

Three sites have been chosen, with seacoast atmospheres representing the major bodies of water surrounding Continental United States.

Atlantic Coast: Kure Beach, N. C.—This site is adjacent to the well-known test facilities operated by The International Nickel Co. at Kure Beach, N. C., and is made available by agreement with that company and the Ethyl Dow Chemical Co. At least an acre is available and some tests have been started including the extensive "light metal" program of Committee B-7.

Gulf Coast: Freeport, Tex.—Arrangements for a site in this area are also in a preliminary state. The area in mind is located in the flood gate area at the mouth of the Brazos River.

Pacific Coast: Point Reyes, Calif.—Arrangements have been completed with American Telephone and Telegraph Co. for the use of approximately one acre of land on their property at Point Reyes, Calif., about 30 miles north of San Francisco. This is an ideal location representative of typical fog conditions of that region. Preliminary construction of facilities envisages future exposure of 7000 specimens.

Canal Zone:

Mild Tropical.—Arrangements have been completed with the Panama Canal Zone authorities for the use of available space at several locations in the Canal Zone, including Gatun, Miraflores, and Cristobal. Tests are under way at the Miraflores location.

Severe Tropical.—Facilities have been made available at the Naval Research Laboratories' grounds at Fort Sherman. Fort Sherman is located on the West Coast (Atlantic Ocean side) on the Canal Zone.

Canadian Test Sites:

The Advisory Committee on Corrosion and the National Research Council of

Canada have agreed to the reciprocal use of test sites under their respective jurisdictions. The Canadian Council has established sites at Halifax ((1) pure marine and (2) industrial-marine), Ottawa (rural), Montreal (industrial), and Saskatoon (rural). Consideration is also being given to the establishment of sites on Vancouver Island and at Bakers Lake 150 miles northwest of Churchill, Man., in the Far North. The ACC has been advised that space could be made available at any of these sites.

Other sites may be considered at some future time, but it is believed that those now selected will adequately meet the Society's long-time requirements for atmospheric exposure testing.

IMMERSION TESTS

The Society's long-range program on exposure tests includes the establishment of several underwater sites. Tentative arrangements have been made for the use of a part of the seawater test dock used by The International Nickel Co. at Harbor Island, N. C.

FINANCIAL SUPPORT

The Advisory Committee on Corrosion estimated that the cost of acquiring, maintaining, and supervising the ASTM Exposure Test Sites for the first ten years would be at least $100,000. This cost includes equipping the sites with test facilities—test racks, specimen frames, and various special items—enclosing them where necessary, and providing a qualified engineer from Society headquarters staff to give the necessary technical supervision and to superintend the maintenance of the sites and test specimens under the general guidance of the Advisory Committee and the various technical committees sponsoring the exposure tests. Centralization of this latter service is essential to the efficient operation of the whole program and will relieve committee officers and members of burdensome detail—including the not inconsiderable expense involved—which with the rapid growth of the program, they could no longer handle effectively. The estimate of $100,000 does *not* include cost of test specimens, such special test racks as may be required, mounting and removal of specimens, or expenses of committee members incurred in any phase of the test programs. The cost of publishing reports of the tests will, as heretofore, be met from general funds of the Society.

The response to invitations for support of this Society-wide program was extremely gratifying. As of June 20, 1952, a total of $103,650 had been pledged by the following 148 companies:

Acme Steel Co.
Alan Wood Steel Co.
Allegheny Ludlum Steel Corp.
Allied Research Products, Inc.
Allis-Chalmers Mfg. Co.
Aluminum Company of America
Aluminum and Magnesium, Inc.
American Bureau of Shipping
American Chemical Paint Co.
American Cyanamid Co.
American Steel Foundries
American Viscose Corp.
American Zinc Institute, Inc.
Apex Smelting Co.
Armco Steel Corp.
Atlantic Refining Co.
Automatic Electric Co.
Babcock & Wilcox Co.
Babcock & Wilcox Tube Co.
Baker Castor Oil Co.
Ball Chemical Co.
Baltimore & Ohio Railroad Co.
Barnes-Bigson Raymond Div. of Assoc. Spring Corp.
Bell Telephone Laboratories, Inc.
Bethlehem Steel Co., Inc.
Bohn Aluminum and Brass Corp.
Bonney-Floyd Co.
Boston Edison Co.
Braun & Co., C. F.
Briggs & Stratton Corp.
Brown Co., R. J.
Bundy Tubing Co.
Burndy Engineering Co., Inc.
Burroughs Adding Machine Co.
Canadian Pacific Railway Co.
Carpenter Steel Co.
Catalin Corp. of America
Caterpillar Tractor Co.
Celanese Corp. of America
Christiansen Corp.
Chrysler Corp.
Cities Service Co.
Colorado Iron and Steel Corp.

Columbian Carbon Co.
Conmar Products Corp.
Consolidated Gas Electric Light & Power Co. of Baltimore
Continental Diamond Fibre Co.
Continental Steel Corp.
Cook Paint and Varnish Co.
Copperweld Steel Co.
Crucible Steel Co. of America
Deere and Co.
Detroit Steel Products Co.
Diamond Alkali Co.
Dow Chemical Co.
Driver Co., Wilbur B.
du Pont de Nemours, Inc., E. I.
Duquesne Light Co.
Durez Plastics and Chemicals, Inc.
Eastern Stainless Steel Corp.
Elastic Stop Nut Corp. of America
Electric Steel Foundry Co.
Enterprise Paint Mfg. Co.
Falk Corp.
Fuller and Co., The W. P.
Gates Rubber Co.
General Electric Co.
General Motors Corp.
General Railway Signal Co.
Grand Rapids Varnish Corp.
Granite City Steel Co.
Gulf Research and Development Co.
Handy & Harman
Hanson-Van Winkle-Munning Co.
Hardesty & Hanover
Harshaw Chemical Co., The
Hercules Powder Co.
Hodgman Rubber Co.
Hunter Douglas Corp.
Hydro-Electric Power Commission of Ontario
Imperial Paper and Color Corp.
Indiana Steel and Wire Co.
Inland Steel Co.
International Harvester Co.
International Nickel Co., Inc.
Irvington Varnish and Insulator Co.
Johns-Manville Corp.
Jones & Laughlin Steel Corp.
Joslyn Mfg. and Supply Co.
Kaiser Aluminum and Chemical Corp.
Kaiser Steel Corp.
Spencer Kellogg and Sons, Inc.
Kerite Co.
Laclede Steel Co.
Lakeside Malleable Castings Co.
Lebanon Steel Foundry
Lilly Varnish Co.
Lloyd's Register of Shipping
Lockheed Aircraft Corp.
Lowe Brothers Co.
Lukens Steel Co.
Maas & Waldstein Co.
Manning, Maxwell & Moore, Inc.
National Cash Register Co.
Naylor Pipe Co.
New Products Corp.
Niagara Mohawk Power Corp.
Norfolk & Western Railway Co.
Nuodex Products Co.
Ohio Brass Co.
Parker Rust-Proof Co.
Pennsylvania Forge Co.
Pittsburgh Steel Co.
Plaskon Div., Libbey-Owens-Ford Glass Co.
Pratt & Lambert, Inc.
Publicker Industries, Inc.
Pure Oil Co.
RCA Labs., Radio Corp. of America
Reichhold Chemicals, Inc.
Republic Steel Corp.
Revere Copper & Brass, Inc.
Reynolds Metals Co.
Sargent & Lundy
Sears, Roebuck and Co.
Shell Development Co.
Singmaster & Breyer
Southern Electrical Corp.
Southern Railway System
Sperry Gyroscope Corp.
Standard Oil of California
Standard Oil Development
Superior Die Casting Co.
Sylvania Electric Products, Inc.
Tennessee Eastman Corp.
Thiokol Corp.
Titan Metal Manufacturing Co.
Twitchell, Inc., E. W.
Udylite Corp.
Union Carbide & Carbon Research Laboratories, Inc.
United Chromium, Inc.
United Co-operatives, Inc.
U. S. Steel Corp.
Utilities Research Commission
Vanadium Corp. of America
Westinghouse Air Brake Co.
Westinghouse Electric Corp.
Whitney Blake Co.
Youngstown Sheet & Tube Co.

Contributions from these companies range up to $5000, spread over a period of years or given in one sum as the companies preferred. A number of other companies are considering an invitation to contribute.

As indicated above, $100,000 was the

estimated minimum for ten-years' operation. Any contributions in excess of this amount will be used to extend the program or may be needed to supplement the present estimate should cost of materials and labor continue to increase.

Any companies or individuals that have not been approached and would like to aid in the financial support of this program may do so simply by mailing their contributions to the Treasurer of the Society, 1916 Race St., Philadelphia 3, Pa. Checks should be drawn to the order of the "ASTM Test Site Fund." All contributions will be gratefully acknowledged.

USE OF TEST SITES OTHER THAN BY ASTM COMMITTEES

Naturally the majority of exposure programs will be committee sponsored. There may be instances, however, when groups or individuals other than ASTM committees may wish to use ASTM test site facilities. Each request for the use of such facilities is considered individually by the Advisory Committee on Corrosion and the applicant must agree to comply with the "Rules Governing Use of ASTM Exposure Test Sites Other than by ASTM Committees" (see Appendix II).

SUMMARY

The great value to industry of the Society's findings on the properties of materials in resisting corrosion and other forms of deterioration has long been recognized. The cooperative nature of this work, with participation of both producer and consumer interests, as well as the careful planning and critical evaluation of results, has led to a wide acceptance of ASTM data as engineering facts that can be relied upon in design of structures and equipment, and to the development of many authoritative specifications that are very generally used throughout industry. We are confident, therefore, that the Society's enlarged program of exposure testing described in this article will receive the wholehearted support of our ASTM membership, and in confident anticipation of such support the Advisory Committee on Corrosion is proceeding with the program.

Respectfully submitted on behalf of the committee,

F. L. LaQue,
Chairman.

J. S. Pettibone,
Secretary.

APPENDIX I

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APPENDIX II

RULES GOVERNING USE OF ASTM EXPOSURE TEST SITES OTHER THAN BY ASTM COMMITTEES

The American Society for Testing Materials established in 1941 the Advisory Committee on Corrosion, which committee is responsible for the acquisition and maintenance of ASTM exposure test sites and the review of all proposed exposure programs at these sites. This review includes tests sponsored by ASTM Technical Committees and by others who wish to use ASTM test site facilities.

1. All applications for use of ASTM test site facilities shall be made in writing to Advisory Committee on Corrosion or to the Executive Secretary of the Society. If the Advisory Committee on Corrosion approves the application, it will so advise the Executive Secretary of the Society who will inform the applicant and conclude the arrangements. Such arrangements shall include a letter form agreement setting forth (*a*) test rack location or locations, (*b*) the specific test rack structures or locations within the test sites, (*c*) the definite period of time for which permission is granted to use the ASTM facilities, and (*d*) agreement by the applicant to abide by these Rules Governing Use of Exposure Test Sites Other than by ASTM Committees.

2. The materials or products to be exposed and the purpose for which the test is made shall be within the scope of

the American Society for Testing Materials. The materials or products shall be described and characterized by adequate laboratory and inspection tests approved by the Advisory Committee on Corrosion, and not identified by brand names, trade names, or similar terminology.

3. The form and size of the exposure specimens shall be acceptable to the Advisory Committee on Corrosion and in keeping with the space available at the site. The committee shall also approve the details of specimen exposure, such as method of attachment, spacing of specimens on the test racks, location on the racks to avoid sheltering or shielding of other exposure tests, size of specimens, etc. All expenses in connection with the preparation of specimens, special supporting structures and attachment devices of any kind, transportation charges to the site, erection, etc., shall be borne by the applicant. The applicant shall submit to the committee for approval a statement of the methods that he proposes to use in inspecting the materials or products exposed.

4. The applicant shall notify the committee one month in advance of making any inspection and obtain approval of the time selected.

5. The committee, at its discretion, may require the presence of a representative of the committee when exposure, inspection, or removal of specimens is to be made. Traveling and living expenses of the committee's representative shall be borne by the applicant.

6. The applicant shall make available to the Advisory Committee on Corrosion the results of its inspection test reports, etc., and agree to publication of such inspection data in the ASTM BULLETIN or other Society publications if so desired by the committee. The applicant agrees not in any way to publish, advertise, identify, or compare his materials or products exposed at the ASTM test site with any particular set of test results in ASTM publications, unless the written approval of the Executive Secretary of the Society is secured.

7. The applicant shall agree to reimburse the Society for any damages to the test racks, or to other specimens exposed on the test racks, or to enclosure fences surrounding the ASTM test site, as a result of the applicant's exposure test or visits to the test site by the applicant's personnel.

8. In case the applicant fails to abide by any of the rules outlined above, the Society reserves the right to terminate its agreement forthwith and remove from the test site any of the applicant's materials or products remaining therein.

9. If the application is granted, the Society assumes no responsibility for any damage to the applicant's specimens, nor for injury to any of the applicant's personnel engaged in erecting, inspection, or removing specimens.

Approved by ASTM Board of Directors January 16, 1951.

REPORT OF JOINT COMMITTEE

ON

EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS

During the past year, the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals, together with its Panels and Subcommittees, held two business sessions, both at Atlantic City, one on June 19, 1951, at the time of the Annual Meeting of the American Society for Testing Materials, and the other on November 27 at the time of the Annual Meeting of The American Society of Mechanical Engineers.

During the June meeting, meetings were held by the Aviation Panel, Gas Turbine Panel, General Research Panel, Data and Publications Panel, Petroleum and Chemistry Panel, Low Temperature Group, Project 29, and the Technical Advisory Committee, preceding the meeting of the Joint Committee itself.

During the November meeting, there were meetings held by the Aviation Panel, General Research Panel, Data and Publications Panel, Petroleum and Chemistry Panel, Gas Turbine Panel, Low Temperature Group, and Steam Power Panel, in addition to the meetings of the Technical Advisory Committee and the Joint Committee itself.

Technical Sessions and Papers:

During the Annual Meeting of the ASME in November, a technical session was sponsored at which the following four papers[1] were presented:

"A Time-Temperature Relationship for Rupture and Creep Stresses," by Frank R. Larson, Watertown Arsenal, and James Miller, General Electric Co.,

"Effects of Temperature Variation on the Long Time Rupture Strength of Steels," by Ernest L. Robinson, General Electric Co.,

"High Temperature Stress Rupture Testing of Tubular Specimens," by Lambert F. Kooistra, Robert U. Blaser, and James T. Tucker, Jr., The Babcock & Wilcox Co.,

"Rupture and Creep Characteristics of Titanium-Stabilized Stainless Steel at 1100 to 1300 F," by James W. Freeman, University of Michigan; George F. Comstock, National Lead Co.; and A. E. White, University of Michigan.

Copies of these papers will be sent to all contributors to the current financial campaign being conducted by the Joint Committee.

During the Semi-Annual Meeting of ASME in June in Cincinnati, Ohio, one session is being sponsored by the Steam Power Panel at which the following two papers are being presented:

"Operating Experiences on the Mechanical Joint Connecting Austenitic-Ferritic Materials in the Main Steam Line at Ridgeland Station," by E. C. Bailey, Commonwealth Edison Co.; H. C. Schroeder, Sargent and Lundy; and I. Carlson, Crane Co., and

"Comparison at Elevated Temperatures of Some Commercial Grades of Ferritic Cast Steels," by H. W. Wyatt, J. W. Bolton, and M. L. Steinbuch, The Lunkenheimer Co.

During the Golden Anniversary Meeting of ASTM in June in New York, a symposium[2] covering three sessions is being sponsored jointly by the Gas Turbine Panel and the General Research Panel on Effects of Notches and Metallurgical Changes on the Strength and Ductility of Metals at Elevated Temperatures. The following twelve papers are being presented:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] *Transactions*, Am. Soc. Mechanical Engrs., Vol. 74, No. 5, July, 1952, pp. 765–801.

[2] This "Symposium on Effects of Notches and Metallurgical Changes on Strength and Ductility of Metals at Elevated Temperatures" will be published as a special technical publication, *STP No. 128*.

"A Survey of Embrittlement and Notch Sensitivity of Heat-Resisting Steels," by George Sachs, Syracuse University, and W. F. Brown, Jr., N.A.C.A.,

"Effect of a Notch and of Hardness on the Rupture Strength of 'Discaloy'," by F. C. Hull, E. K. Hann, and H. Scott, Westinghouse Electric Corp.,

"The Influence of Sharp Notches on the Stress Rupture Characteristics of Several Heat-Resisting Alloys," by W. F. Brown, Jr., M. H. Jones, and D. P. Newman, N.A.C.A.,

"The Effect of Grain Size Upon the Fatigue Properties at 80, 1200, and 1600 F of the 'Precision-Cast' Co-Cr-Ni-W Alloy X-40," by P. R. Toolin, Westinghouse Electric Corp.,

"Investigations into the Effect of Notches on the Results of Long-Time Rupture Tests at the Elevated Temperatures," by W. Siegfried, Sulzer Bros., Ltd.,

"Theory of Time Dependent Rupture and Interpretation of Some Stress-Rupture Data," by D. N. Frey, Ford Motor Co.,

"Effect of Notch Geometry on Rupture Strength at Elevated Temperatures," by E. A. Davis and M. J. Manjoine, Westinghouse Electric Corp.,

"An Experimental Study of the Strength and Ductility of Steel at Elevated Temperatures," by J. Glen, Colvilles Ltd.,

"Effect of Sigma on Strength and Ductility of 25 Cr, 20 Ni Steel," by G. V. Smith and E. J. Dulis, United States Steel Co.,

"Recovery and Creep in an Alloy Steel," by H. A. Lequear and J. D. Lubahn, General Electric Co.,

"The Structure and Properties of Stainless Steels After Exposure at Elevated Temperatures," by A. B. Wilder and E. F. Ketterer, National Tube Co.,

"Exploratory Investigation of High-Temperature Sheet Materials," by D. Preston, General Electric Co. (a progress report by the Aviation Panel on Project AP2).

Publications:

In January, 1952, the American Society for Testing Materials issued *Special Technical Publication No. 124* entitled Report on the Elevated-Temperature Properties of Stainless Steels, prepared for the Data and Publications Panel by Ward F. Simmons and Howard C. Cross. This is the second report in a series being prepared under the direction of the Panel to furnish modern high-temperature test data to American industry.

The third report in this series will cover both super-alloys and low-alloy ferritic steels. Test results in these groups have been coming in during the past year.

Membership:

During the past year, R. H. Tingey and J. H. Romann have ceased to be members of the Joint Committee and Irving Roberts and D. B. Rossheim have been appointed to membership by the sponsor societies on the recommendation of the committee.

Finances:

Under the chairmanship of N. L. Mochel, the Subcommittee on Finance has been carrying on a campaign to raise funds for the support of projects not being carried on independently by the organizations to which the members of the Joint Committee or its Panels belong and which recognize the advantage of making their results available through the forum of the Joint Committee. Up to June 1, some 75 different organizations had subscribed upwards of $65,000 towards this work. These many cash contributions from all branches of American industry indicate a widespread support of the work being carried on by the Joint Committee and a full appreciation of its importance to the design of modern machinery to operate under extremes of high or low temperature. While the results of this campaign indicate a wide interest in the work of the committee, the size of this account measures only the ready money available to cover work not otherwise paid for. By far the largest volume of development activities is being carried on by the many industrial organizations, universities, and government bureaus represented on the committee.

As in the past, the activities of the Joint Committee continue to enjoy the sponsorship of the Engineering Foundation.

New Contracts:

During the six months following the November meeting, four new contracts for development work under the sponsorship of the Joint Committee have been signed. Two of these contracts cover the extension of work already in progress:

1. Contract with Battelle Memorial Inst. sponsored by Project 29 on The Effect of Certain Elements on the Graphitization of Steels—$600.
2. Contract with Battelle Memorial Inst. sponsored by the Data and Publication Panel on Survey of the High-Temperature Properties of Chromium-Molybdenum Steels and the Super-Alloys—$3000.

The other two contracts are for new work:

1. Contract with Battelle Memorial Inst. sponsored by the Gas Turbine Panel on Project GTP1 on Notched Bar Rupture and Fatigue Test on N-155 Alloy—$3000.
2. Contract with the University of Michigan sponsored by the Aviation Panel, Project AP1A on The Statistical Evaluation of Creep-Rupture Properties of Certain Sheet Materials—$15,000.

ACTIVITIES OF PANELS AND PROJECT SUBCOMMITTEES

Aviation Panel (Leo Schapiro, chairman):

A contract has been completed with the University of Michigan for Project AP1A on The Statistical Evaluation of Creep-Rupture Properties of Certain Sheet Materials.

Project AP2 is presenting a progress report entitled "Exploratory Investigation of High-Temperature Sheet Materials" during the Symposium on Effects of Notches and Metallurgical Changes on the Strength and Ductility of Metals at Elevated Temperatures[2] at the Golden Anniversary Meeting of ASTM in New York.

Mr. Olcott has ceased to be a member of the Panel and with the approval of the Technical Advisory Committee, the Bureau of Aeronautics and Air Development Center have been invited to name members.

Data and Publications Panel (R. F. Miller, chairman):

During the past year, ASTM *Special Technical Publication No. 124*, Report on the Elevated Properties of Stainless Steels, was issued under the sponsorship of this Panel.

The Panel is currently collecting and compiling data on the high-temperature properties of chromium-molybdenum and super-alloys.

A survey patterned after Project 16 on Relaxation Data is being initiated under the chairmanship of Mr. S. Low.

A survey on copper-base alloys is being undertaken and $1000 has been earmarked for this project.

Gas Turbine Panel (C. T. Evans, Jr., chairman):

A contract with Battelle Memorial Inst. for carrying on Project GTP1 on Notched Bar Rupture and Fatigue Tests on N-155 Alloy has been completed.

The Symposium[2] at the ASTM Golden Anniversary Meeting on Effects of Notches and Metallurgical Changes on Strength and Ductility of Metals at Elevated Temperatures is being sponsored jointly by this Panel and the General Research Panel.

With the approval of the Technical Advisory Committee, E. O. Dickson, Ladish Co., Jack Succop, Heppenstall Co., and D. N. Frey, Ford Motor Co., were invited to join the Panel.

General Research Panel (*A. J. Herzig, chairman*):

Jointly with the Gas Turbine Panel, the General Research Panel has arranged for the Symposium[2] being held at the ASTM Golden Anniversary Meeting.

Petroleum and Chemical Panel (*C. L. Clark, chairman*):

Project No. 2 on The Behavior of Materials at Very Low Temperatures has been organized as a separate panel under the chairmanship of Irving Roberts.

Project No. 6 on Graphitization in the Petroleum and Chemical Industries has prepared an initial report and the group has been discharged. A new project is being organized to carry on this work.

Project No. 8 on the High-Temperature Strength of Commercial Grades of Carbon-Steel Plate and Pipe has prepared a progress report. The program of this project is nearing completion.

Steam Power Panel (*N. L. Mochel, chairman*):

The Steam Power Panel is sponsoring a symposium at the ASME Semi-Annual Meeting in Cincinnati in June, 1952.

Low Temperature Panel (*Irving Roberts, chairman*):

Activity in the low-temperature field, which was formerly carried on as a Subgroup of the Petroleum and Chemical Panel, has now been organized as a separate panel.

Test Methods Panel (*J. J. Kanter, chairman*:

The Panel on Test Methods is made up of one representative from each of the other Panels. The Test Methods Panel is currently reviewing the three ASTM Standards sponsored by the Joint Committee: namely,

Recommended Practice for Short-Time Elevated-Temperature Tension Tests of Metallic Materials (E 21 – 43),

Recommended Practice for Conducting Long-Time High-Temperature Tension Tests of Metallic Materials (E 22 – 41), and

Tentative Recommended Practice for Conducting Time for Rupture Tension Tests of Metallic Materials (E 85 – 50 T).

Stability of Steels as Affected by Temperature—Project 29 (*J. J. Kanter, Chairman*):

The contract recently completed with Battelle Memorial Inst. is expected to complete this work on the fundamental aspects of the susceptibility of steels to graphitization.

Respectfully submitted on behalf of the committee,

ERNEST L. ROBINSON,
Chairman.
F. B. FOLEY,
Vice-Chairman.

H. C. CROSS,
Secretary.

REPORT OF COMMITTEE C-1
ON
CEMENT*

Committee C-1 on Cement held three meetings during the past year: in Atlantic City, N. J., June 20, 1951; at West Lafayette, Indiana, October 26, 1951; and in Cleveland, Ohio, March 5, 1952. Purdue University very kindly arranged for the October meeting to be held in the University's Memorial Union Building and generously aided in making the meeting memorably pleasant and successful.

The committee records with sorrow the deaths of these long-time members, J. Clifford Evans, Meyer Hirschthal, and G. L. Lindsay.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. R. Litehiser.

Vice-Chairman, W. C. Hanna.

Secretary, W. S. Weaver.

Six Members at Large of the Advisory Committee, L. R. Forbrich, F. H. Jackson, W. H. Klein, P. D. Miesenhelder, C. H. Scholer, E. J. Wechter.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specification for:

Air-Entraining Portland Cement (C 175 – 50 T), and

Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (C 226 – 50 T).

Revision of Tentative Method of:

Chemical Analysis of Portland Cement (C 114 – 48 T), and

Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 – 50 T).

Revision of Tentative Definition of:

The Term Addition as Applied to Hydraulic Cements (C 219 – 48 T).

Tentative Revision of Standard Specifications for:

Portland Cement (C 150 – 49).

Tentative Revision of Standard Method of:

Chemical Analysis of Portland Cement (C 114 – 47), and

Test for Autoclave Expansion of Portland Cement (C 151 – 49).

These recommendations were accepted by the Standards Committee under its actions of September 12, 1951, and January 5, 1952, and appear in the 1951 Supplement to Book of ASTM Standards, Part 3.

REVISION OF STANDARD, IMMEDIATE ADOPTION

Standard Method of Test for Compressive Strength of Hydraulic Cement Mortars **(C 109 – 50).**[1]—The committee recommends revision, for immediate adoption, of this standard, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be offered to letter ballot of the Society. The change is highly desirable in order to provide an adequate batch of mortar for the manufacture of nine cubes. No controversial point is involved. This change would be in line with proposed action in Federal Specifications, and such uniformity in methods is highly desirable. This change is as follows:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 3.

Section 8(a).—Revise the third sentence to provide for the use of 740 g (instead of 700 g) of cement and 2035 g (instead of 1925 g) of graded standard sand.

Method of Test for Autoclave Expansion of Portland Cement (**C 151 – 49**).[2]—The committee recommends revision, for immediate adoption, of this standard, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society. It has been concluded that it would be very helpful to numerous laboratories if, in routine tests, shorter test specimens than the standard autoclave bar could be used. Accordingly, the following revision is recommended:

Section 2(c).—Insert the following note immediately after the present first sentence:

> NOTE.—In routine tests, 1 by 1 by $6\frac{1}{4}$-in. specimens with an effective gage length of 5 in. may be used, but in case of dispute, results obtained with 1 by 1 by $11\frac{1}{4}$-in. specimens of 10-in. effective gage length shall govern.

REVISION OF TENTATIVES

Tentative Method of Test for the Potential Alkali Reactivity of Cement-Aggregate Combinations (**C 227 – 51 T**).[3]—The committee recommends the acceptance of the following revision in Tentative Method C 227 – 51 T. This recommended revision provides for a desirable increase in the amount of mixing water in the mortar and is based on the results reported by T. E. Stanton in his 1951 ASTM paper entitled "Report on Further Studies to Develop an Accelerated Test Procedure for the Detection of Adversely Reactive Cement-Aggregate Combinations,"[4] and on the results of later tests made by the Research Laboratory of the Portland Cement Assn. The revision is as follows:

Section 5(c).—Revise the last sentence to read as follows:

> The amount of mixing water measured in milliliters shall be such as to produce a flow of 105 to 120 (as determined in accordance with Section 9 of the Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109) except that the flow table shall be given ten $\frac{1}{2}$-in. drops in approximately 6 sec instead of twenty-five $\frac{1}{2}$-in. drops in 15 sec), and shall be expressed as a percentage by weight of the cement.

Tentative Method of Test for Time of Setting of Hydraulic Cement in Mortar (**C 229 – 51 T**).[3]—The committee recommends the acceptance of the following two changes in order to secure an improved description of the apparatus:

Section 2(e).—Change first twelve lines to read as follows:

> The penetration apparatus used for measuring consistency shall be similar to the Vicat apparatus described in Section 2(*d*) of the Tentative Method of Test for Time of Setting of Hydraulic Cement by the Vicat Needle (C 191 T) except that it shall be modified as follows: The plunger shall have a total weight of 400 ± 0.5 g and be fitted with a brass rod $\frac{11}{16} \pm 0.002$ in. in diameter by $2\frac{1}{8} \pm 0.05$ in. in length on one end for measuring consistency.

Section 2(f).—Substitute the following for the first two sentences:

> The regular Vicat apparatus described in Section 2(*d*) of the ASTM Tentative Method of Test C 191 T shall be used, except that a 2 ± 0.05-mm. stainless steel needle shall be substituted for the 1-mm. needle, and the total weight of the plunger readjusted to 300 g.

Tentative Specification for Flow Table for Use in Tests of Hydraulic Cement

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[2] 1949 Book of ASTM Standards, Part 3.

[3] 1951 Supplement to Book of ASTM Standards, Part 3.

[4] *Proceedings*, Am. Soc. Testings Mats., Vol 51, p. 1087 (1951).

(C 230 – 49 T).[2]—The committee recommends the acceptance of the following revisions in order to provide better requirements for the apparatus:

Section 3(a).—After the third sentence, insert the following:

> The pedestal shall be cast inverted on the base plate so as to ensure a positive contact between the base plate and the pedestal at all points. No nuts or other such levelling devices shall be used between the plate and the pedestal. Levelling shall be effected by suitable means under the base of the pedestal.

Rewrite the final sentence as follows:

> The pedestal shall be of monolith construction and shall weigh at least 300 lb. Sound-deadening material not over ½ in. thick consisting of stable cork gasket pads approximately 4 in. square may be inserted under each corner of the pedestal if desirable. When using this material, it will be necessary to check the flow table for levelness frequently.

Figure 1.—Include tolerances in the two diameters and the height of the mold so that these dimensions will read: "2.75 ± 0.02 in., 4.00 ± 0.02 in., and 2.00 ± 0.02 in." Note 2, add: "Motor drive mechanism shall not be fastened or mounted on table base plate or frame."

Tentative Method of Test for Bleeding of Cement Pastes and Mortars (C 243 – 50 T).[1]—The committee recommends the acceptance of the following revisions in order to clarify the procedure and to cover the use of the centering ring and depth gage currently being supplied with the apparatus by one instrument maker. The recommended revisions are as follows:

Section 7(a).—Change the third sentence to read:

> The collecting ring shall be placed approximately in the center of the paste surface and embedded to a depth of approximately ¼ in. (Note 1) and the surface of the paste covered with carbon tetrachloride (Note 2) to a depth of about 1¼ in.

At the end of the section, add the following new Note:

> NOTE 1.—When using equipment including a centering ring and ring depth gage, remove these before adding the carbon tetrachloride.

Renumber the present Note as "Note 2."

Tentative Specifications for Natural Cement (C 10 – 49 T).[2]—The committee recommends the acceptance of the following revision.

Section 11(e): *Time of Setting*.—Replace the currently specified test method, Tentative Method of Test for Time of Setting of Hydraulic Cement in Mortar (C 229 T), by Tentative Method of Test for Time of Setting of Hydraulic Cement by Vicat Needle (C 191 – 51 T).

Table I.—Retain the present setting time limits unchanged, but delete the words "of natural cement in mortar" in order to be consistent with Tentative Method C 191.

(NOTE.—Elsewhere in this report, Tentative Method C 191 is being recommended for adoption as standard.)

ADOPTION OF TENTATIVE REVISION AS STANDARD

Standard Specifications for Portland Cement (C 150 – 49).[3]—The committee recommends the adoption as standard of the following portions of the tentative revisions that have been issued during the past two years. The portions are here repeated for ready reference:

1. The tentative revision that added to Table II the requirement: "Air content of mortar, prepared and tested in accordance with Method C 185, maximum per cent by volume, less than 15.0 for all types."

2. The tentative revision issued June, 1949 (not the modified revision of September, 1950) that changed the last sentence of footnote *c* under Table II to read: "If, at the option of the purchaser, a 7-day test is required on type

III cement, the strength at 7 days shall be higher than at 3 days."

3. The tentative revisions issued January 5, 1952, that revised the time of setting requirements in Table II and changed the wording in the second sentence of footnote *b*.

WITHDRAWAL OF STANDARD

Standard Methods of Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles (**C 191 – 49**).—The Vicat portion of this method was made the subject of a new tentative method (C 191 – 51 T), which is being recommended later in this report for adoption as standard; the Gillmore part of the test has been made the subject of new Tentative Method C 266 – 51 T. Accordingly, the committee recommends the withdrawal of the current Standard Method C 191 – 49.

ADOPTION OF TENTATIVE AS STANDARD

Tentative Method of Test for Time of Setting of Hydraulic Cement by Vicat Needle (**C 191 – 51 T**).—The committee recommends the adoption as standard of this tentative, which is almost identical with the corresponding part of The Standard Method C 191 – 49, which has been recommended for withdrawal earlier in this report.

TENTATIVES AND STANDARDS CONTINUED WITHOUT REVISION

Based on recent considerations of the specifications and test methods described below, and also on current study of related work now in progress in the various subcommittees, the committee recommends that the following tentatives and standards be retained in their present status without revision at this time:

Tentative Methods of:

Chemical Analysis of Portland Cement (C 114 – 51 T),
Test for Air Content of Hydraulic Cement Mortar (C 185 – 50 T), and
Test for Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry (C 228 – 49 T).

Tentative Revision of:

Method of Test for Heat of Hydration of Portland Cement (C 186 – 50 T).

Standard Specifications for:

Natural Cement (C 10 – 37).

Standard Method of Test for:

Fineness of Portland Cement by the Turbidimeter (C 115 – 42),
Sampling Hydraulic Cement (C 183 – 46),
Fineness of Hydraulic Cement by the No. 200 Sieve (C 184 – 44), and
Specific Gravity of Hydraulic Cement (C 188 – 44).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

The various subcommittees have been engaged in studying their respective problems, and some of their work is here briefly described.

Particularly interesting to the C-1 members is the work of the Fiftieth Anniversary Subcommittee, which consists of W. H. Klein (chairman), Joseph Brobston, F. H. Jackson, R. H. Fasnacht, H. L. Kennedy, C. T. Raber, and M. A. Swayze. The organization meeting of Committee C-1 was held in Philadelphia on October 31, 1902, and Committee C-1 plans to hold an Anniversary Meeting in Philadelphia this year. Mr. Klein's subcommittee is preparing an appropriate program for the occasion.

The *Sponsoring Committee on Portland Cement* (C. H. Scholer, chairman) has been studying numerous questions relating to specifications and has contributed a number of recommendations affecting standards.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

At the Annual Meeting in June, 1952, the Sponsoring Committee requested that the tentative revisions issued January 5, 1952, pertaining to time of setting requirements, be adopted as standard to eliminate confusion resulting from the recommendation for the withdrawal of C 191 - 49 and to conform to the same requirements as now incorporated in the Tentative Specifications for Air-Entraining Portland Cement (C 175-51 T). Since this action was not included in the Report of Committee C-1 as preprinted, approval for such action was obtained from the Executive Committee of the Board of Directors.

The *Sponsoring Committee on Masonry Cement* (E. J. Wechter now chairman, succeeding H. L. Vanderwerp who had been chairman earlier in the year) has been studying a number of important questions relating to the specifications for masonry cement. Special interest is attached to the current study of the results of autoclave tests on such cements, and it is anticipated that the subcommittee will very soon make recommendations as to appropriate limits for autoclave expansion of masonry cements.

The *Sponsoring Committee on Blended Cement* (L. R. Forbrich, chairman) has been studying the results of tests by 5 laboratories on 20 samples of fly ash. The subcommittee has been considering proposed tentative specifications for portland-pozzolan cement and for materials other than fly ash for use in pozzolan cements.

The *Editorial Subcommittee* (W. J. McCoy, chairman) has continued to cooperate with the appropriate subcommittees relative to editorial questions growing out of the reviews of proposed new test methods or revisions in standards.

The *Working Committee on Methods of Chemical Analysis* (W. C. Hanna, chairman) presented a number of revisions in current methods. Comparative tests are now in progress in the study of several methods for the removal of manganese in the course of chemical analysis of cement. Cooperative tests are being made in a study of Method C 228 T designed to adapt the method so that a number of designs of flame photometers might be used for the determinations under that method.

The *Working Committee on Volume Change and Soundness* (H. F. Gonnerman, chairman) offered a number of recommendations affecting Methods C 151 and C 227 T. The subcommittee has been studying important questions relating to the design and operation of autoclaves.

The *Working Committee on Sulfate Resistance* (D. Wolochow, chairman) has been studying the data accumulated in a series of cooperative tests of 13 cements by 17 laboratories, and a supplementary series of tests was arranged to include types I and III cements.[6]

The *Working Committee on Time of Setting* (E. E. Berger, chairman) submitted a number of recommended revisions in methods, and has been engaged in studying the details of methods.

The *Working Committee on Heat of Hydration* (W. J. McCoy, chairman) has been studying the results of a recent cooperative series of tests in which a number of laboratories compared the current heat of hydration test with a proposed rapid, simplified method.

The *Working Committee on Bleeding, Plasticity, and Workability* (H. L. Kennedy, chairman) recommended certain revisions of methods. Cooperative tests have been made. Several methods of evaluating plasticity and workability are being studied. The relative merits of machine mixing *versus* hand mixing are being studied.

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[6] See p. 250.

The *Working Committee on Fineness* (R. L. Blaine, chairman) has been studying certain details of the turbidimetric fineness test and the air-permeability fineness test. Cooperative tests were planned for studying some of the fineness questions, including the use of the Lea-Nurse apparatus for use with a wide variety of materials.

The *Working Committee on Strength* (C. E. Wuerpel, chairman, succeeding G. L. Lindsay who had been the previous chairman) has been studying details of methods and apparatus. The subcommittee distributed to Committee C-1 tentative drafts of a test for flexural strength of mortars, and also a test for the compressive strength of mortar using the portions of prisms broken in flexure.

The *Working Committee on Additions* (H. W. Russell, chairman) recommended revisions affecting definition of additions and the specifications therefor. The subcommittee is currently studying a number of important questions relating to the specifications for additions.

The *Working Committee on Coordination of Methods of Test* (J. R. Dwyer, chairman) has given study to certain details relating to methods and apparatus.

The *Working Committee on SO_3 Content* (H. S. Meissner, chairman) prepared instructions for use in determining the optimum gypsum content for any given cement and has been awaiting additional test data from cement manufacturers. The subcommittee has cooperated with other subcommittees in related work.

The *Working Committee on Methods of Test for Air-Entrainment* (H. K. Cook, chairman) has been engaged in compiling and analyzing the large amount of data resulting from the extensive series of cooperative tests on a number of cements. Study is being given to important details of Method C 185 T. The relative merits of machine mixing and hand mixing of the standard mortars are being studied.

The *Subcommittee on Cement Reference Laboratory* (G. E. Warren, chairman) reported that the laboratory has been inspecting cement laboratories as the important part of its regular work, and has for the first time visited some of the interested Canadian laboratories. Tolerances for apparatus have been studied, and consideration has been given to questions related to the recent extension of the work to cover certain details of concrete testing. A new lot of flow table calibration material has been prepared for early distribution, including the oil that is to be used. The laboratory has aided in editorial work on the cement standards and has handled the usual correspondence on cement testing apparatus and methods. Contact has been maintained with the various meetings of Committees C-1 and C-9 and with certain other technical committees related to the laboratory's work.

This report has been submitted to letter ballot of the committee, which consists of 89 voting members, of whom 77 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. R. LITEHISER,
Chairman.

W. S. WEAVER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (C 226 – 51 T).

Tentative Revision of Standard Specifications for:

Masonry Cement (C 91 – 51).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the revised tentative and tentative revision appear in the 1952 Book of ASTM Standards, Part 3.

APPENDIX

DETERMINATION OF THE SULFATE RESISTANCE OF PORTLAND CEMENT*

By David Wolochow[1]

This paper, a report of the Working Committee on Sulfate Resistance of ASTM Committee C-1 on Cement, presents the results of a cooperative test program in which two proposed methods for determining the sulfate resistance of portland cement were studied. Outlines of the two methods are appended to the paper.

The disintegration of portland-cement concrete from contact with alkaline sulfate waters is a problem of long standing in many localities. The areas of sulfate waters are sufficiently widespread to justify consideration of sulfate resistance in the specifications for portland cement. The problem has been studied by many investigators during the past thirty years.[2] The chemistry of the reactions is consequently fairly well understood. The problem is recognized in the ASTM Standard Specifications for Portland Cement (C 150 - 49)[3] and Tentative Specifications for Air-Entraining Portland Cement (C 175 - 48 T).[4] In these specifications the sulfate-resistant cements are defined in terms of chemical limitations, type II and type IIA for use in general concrete construction exposed to moderate sulfate action and type V for use when high sulfate resistance is required.

The chemical limitations in the current specifications appear to be adequate for the selection of portland cements that will produce concrete having a high resistance to sulfate waters. However, such chemical limitations do not make allowance for new or improved cement manufacturing procedures or the use of additions such as air-entraining agents, pozzolans or other additions that produce sulfate-resistant cements. A performance test for sulfate resistance would be desirable. The Working Committee on Sulfate Resistance has pursued the development of a performance test for a number of years. The last previous report was published in 1945.[5] The purpose of the present investigation was to assess further the possibilities of the lean mortar bar expansion test and to study a cement sulfate susceptibility test[6] as possible performance tests for sulfate resistance.

Two series of tests were made using thirteen and eleven cements. Two of the cements, Nos. 43 and 51, were the same in both series. These cements were supplied by the Portland Cement Assn. and have been used in the preparation of concrete specimens for storage in sulfate exposure tanks at Sacramento, Calif. In the first series, specimens were also made with air-entraining agent added.

The following seventeen laboratories participated:

Bureau of Public Roads
California Division of Highways
California Portland Cement Co.
Canada Cement Co. Lim.
Cementos Atoyac, S.A.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Secretary, Canadian Government Specifications Board, Ottawa, Canada.

[2] See Bibliography cited by Dalton G. Miller and Phillip W. Manson, "Long-time Tests of Concretes and Mortars Exposed in Sulfate Waters," *Technical Bulletin 194*, Agricultural Experiment Station, University of Minnesota, May, 1951.

[3] 1949 Book of ASTM Standards, Part 3, p. 1.

[4] *Ibid*, p. 5.

[5] Report of Working Committee on Sulfate Resistance, Appendix II, Report of Committee C-1, *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 278 (1946).

[6] W. C. Taylor and R. H. Bogue, "A Sulfate Susceptibility Test for Portland Cements," *Paper No. 58*, Portland Cement Association Fellowship, National Bureau of Standards, September, 1950.

TABLE I.—CHEMICAL COMPOSITION OF CEMENTS.

All values are per cent by weight.

Cement	Major Components							Minor Components								
	SiO_2	Al_2O_3	Fe_2O_3	CaO (Tot.)	MgO	SO_3	Loss on Ign.	Referee Method		Flame Photometer		P_2O_5	TiO_2	Mn_2O_3	Iusoluble Residue	Free CaO
								Na_2O	K_2O	Na_2O	K_2O					
1950 SERIES																
No. 2I	21.88	5.06	4.35	64.05	1.46	1.69	0.87	0.11	0.55	0.11	0.56	0.06	0.53	0.07	0.27	0.35
No. 2L	23.30	4.20	3.53	63.04	1.70	1.67	2.07	0.10	0.48	0.10	0.48	0.11	0.21	0.04	0.38	0.62
No. 2M	22.66	4.35	5.49	63.28	0.88	1.48	0.93	0.11	0.61	0.12	0.62	0.10	0.17	0.22	0.22	0.56
No. 2S	24.04	3.83	3.00	64.03	1.77	1.74	0.87	0.15	0.40	0.16	0.41	0.21	0.17	0.04	0.16	0.79
No. 21	23.77	4.41	3.21	64.63	1.27	1.24	0.68	0.22	0.40	0.23	0.44	0.18	0.23	0.09	0.09	0.65
No. 41	23.02	4.86	4.98	59.60	3.04	1.98	1.26	0.06	1.19	0.03	1.22	0.12	0.23	0.32	0.10	0.44
No. 43	23.56	4.87	4.22	61.66	1.48	1.97	1.06	1.00	0.08	1.06	0.10	0.10	0.25	0.11	0.02	0.12
No. 43A	25.37	3.71	3.06	63.64	1.10	1.87	0.81	0.33	0.01	0.35	0.01	0.10	0.19	0.11	0.04	0.35
No. 5I	23.30	3.94	4.71	63.67	1.18	1.68	0.96	0.08	0.36	0.08	0.37	0.07	0.50	0.07	0.29	0.38
No. 5L	24.22	3.21	3.86	63.90	1.37	1.74	1.21	0.05	0.30	0.05	0.29	0.09	0.14	0.03	0.18	1.06
No. 5M	25.17	3.29	3.65	62.66	1.13	1.74	1.66	0.12	0.40	0.13	0.43	0.08	0.15	0.18	0.24	0.87
No. 5S	25.41	3.18	3.27	63.65	1.48	1.46	1.03	0.13	0.34	0.14	0.36	0.18	0.15	0.03	0.21	0.93
No. 51	24.49	3.35	3.28	64.30	1.73	1.40	0.82	0.08	0.22	0.07	0.27	0.19	0.19	0.09	0.09	0.54
1951 SERIES																
No. 11	20.79	6.07	2.37	63.75	3.65	1.59	1.03	0.21	0.51	0.22	0.56	0.20	0.23	0.07	0.08	0.43
No. 14	22.38	5.02	3.03	63.05	2.50	1.73	0.92	0.06	1.30	0.03	1.40	0.09	0.21	0.13	0.31	0.19
No. 15	20.43	6.09	2.46	67.00	0.78	1.92	0.92	0.08	0.23	0.07	0.25	0.46	0.27	0.07	0.19	0.44
No. 16	21.43	5.05	3.52	64.58	2.05	1.71	1.05	0.23	0.46	0.25	0.46	0.11	0.26	0.13	0.07	0.73
No. 22	22.51	4.94	3.85	62.77	3.17	1.41	0.64	0.24	0.37	0.29	0.39	0.12	0.30	0.07	0.09	0.05
No. 23	21.50	4.89	5.44	64.32	0.92	1.50	0.65	0.59	0.14	0.61	0.14	0.30	0.29	0.07	0.10	0.43
No. 31	20.44	5.40	2.11	64.73	3.29	2.23	1.51	0.23	0.22	0.26	0.26	0.18	0.22	0.09	0.12	1.45
No. 33	20.19	5.52	2.52	65.64	1.44	2.31	1.48	0.21	0.44	0.24	0.46	0.09	0.27	0.06	0.24	1.83
No. 3L	21.56	2.14	5.08	65.66	1.76	2.32	1.20	0.09	0.14	0.08	0.14	0.08	0.10	0.10	0.25	0.35

TABLE II.—OXIDE AND CALCULATED COMPOUND COMPOSITION OF CEMENT CORRECTED FOR FREE CaO ONLY.

Cement	Major Components						Calculated Compounds					C_2F	Free CaO
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$		
1950 SERIES													
No. 2I	21.88	5.06	4.35	63.70	1.46	1.69	47.9	26.6	6.1	13.2	2.9	...	0.35
No. 2L	23.30	4.20	3.53	62.42	1.70	1.67	38.9	37.4	5.2	10.7	2.8	...	0.62
No. 2M	22.66	4.35	5.49	62.72	0.88	1.48	41.8	33.5	2.2	16.7	2.5	...	0.56
No. 2S	24.04	3.83	3.00	63.24	1.77	1.74	39.7	39.0	5.1	9.1	3.0	...	0.79
No. 21	23.77	4.41	3.21	63.98	1.27	1.24	42.0	36.5	6.3	9.8	2.1	...	0.65
No. 41	23.02	4.86	4.98	59.16	3.04	1.98	20.4	50.6	4.5	15.2	3.4	...	0.44
No. 43	23.56	4.87	4.22	61.54	1.48	1.97	27.1	47.2	5.8	12.8	3.4	...	0.12
No. 43A	25.37	3.71	3.06	63.29	1.10	1.87	30.1	50.0	4.7	9.3	3.2	...	0.35
No. 5I	23.30	3.94	4.71	63.29	1.18	1.68	42.5	34.7	2.5	14.3	2.9	...	0.38
No. 5L	24.22	3.21	3.86	62.84	1.37	1.74	39.6	39.5	2.0	11.8	3.0	...	1.06
No. 5M	25.17	3.29	3.65	61.79	1.13	1.74	27.9	51.1	2.5	11.1	3.0	...	0.87
No. 5S	25.41	3.18	3.27	62.72	1.48	1.46	32.0	48.8	2.9	10.0	2.5	...	0.93
No. 51	24.49	3.35	3.28	63.76	1.73	1.40	42.2	38.4	3.3	10.0	2.4	...	0.54
1951 SERIES													
No. 11	20.79	6.07	2.37	63.32	3.65	1.59	51.0	21.1	12.1	7.2	2.7	...	0.43
No. 14	22.38	5.02	3.03	62.86	2.50	1.73	42.8	31.9	8.2	9.2	2.9	...	0.19
No. 15	20.43	6.09	2.46	66.56	0.78	1.92	65.7	9.0	12.0	7.5	3.3	...	0.44
No. 16	21.43	5.05	3.52	63.85	2.05	1.71	53.2	21.3	7.4	10.7	2.9	...	0.73
No. 22	22.51	4.94	3.85	62.72	3.17	1.41	41.5	33.2	6.6	11.7	2.4	...	0.05
No. 23	21.50	4.89	5.44	63.89	0.92	1.50	51.7	22.6	3.8	16.6	2.6	...	0.43
No. 31	20.44	5.40	2.11	63.28	3.29	2.23	56.6	15.9	10.7	6.4	3.8	...	1.45
No. 33	20.19	5.52	2.52	63.81	1.44	2.31	59.0	13.4	10.4	7.7	3.9	...	1.83
No. 3L	21.56	2.14	5.08	65.31	1.76	2.32	71.2	8.1	...	10.2	3.9	2.9	0.35

TABLE III.—OXIDE AND CALCULATED COMPOUND COMPOSITION OF CEMENTS CORRECTED FOR MINOR COMPONENTS.[a]

Cement	Major Components						Calculated Compounds					C_2F	Free CaO
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$		
							1950 SERIES						
No. 2I	21.70	4.38	4.35	63.70	1.46	1.69	53.9	21.6	4.3	13.2	2.9	...	0.35
No. 2L	23.05	3.75	3.53	62.42	1.70	1.67	43.9	33.0	4.0	10.7	2.8	...	0.62
No. 2M	22.51	4.01	5.49	62.72	0.88	1.48	45.2	30.5	1.3	16.7	2.5	...	0.56
No. 2S	23.93	3.40	3.00	63.24	1.77	1.74	43.4	35.9	3.9	9.1	3.0	...	0.79
No. 21	23.71	3.97	3.21	63.98	1.18*	1.24	45.4	33.7	5.1	9.8	2.1	...	0.65
No. 41	22.95	4.48	4.98	59.16	2.72*	1.98	23.5	48.1	3.4	15.2	3.4	...	0.44
No. 43	23.55	4.51	4.22	61.54	1.48	1.97	29.5	45.2	4.8	12.8	3.4	...	0.12
No. 43A	25.34	3.41	3.06	63.29	0.99*	1.87	32.4	48.2	3.9	9.3	3.2	...	0.35
No. 5I	23.10	3.28	4.71	63.29	1.18	1.68	48.5	29.7	0.7	14.3	2.9	...	0.38
No. 5L	24.10	2.92	3.86	62.84	1.37	1.74	42.5	37.0	1.2	11.8	3.0	...	1.06
No. 5M	25.01	2.98	3.65	61.79	1.13	1.74	31.2	48.2	1.7	11.1	3.0	...	0.87
No. 5S	25.27	2.78	3.27	62.72	1.48	1.46	35.7	45.5	1.8	10.0	2.5	...	0.93
No. 51	24.43	2.94	3.28	63.76	1.64*	1.40	45.4	35.8	2.2	10.0	2.4	...	0.54
							1951 SERIES						
No. 11	20.74	5.61	2.37	63.32	3.58*	1.59	54.5	18.4	10.9	7.2	2.7	...	...
No. 14	22.17	4.62	3.03	62.86	2.37*	1.73	47.1	28.1	7.1	9.2	2.9	...	...
No. 15	20.30	5.30	2.46	66.56	0.71*	1.92	72.0	3.9	9.9	7.5	3.3	...	...
No 16	21.38	4.66	3.52	63.85	1.92*	1.71	56.2	18.9	6.4	10.7	2.9	...	...
No. 22	22.45	4.49	3.85	62.72	3.10*	1.41	45.0	30.5	5.4	11.7	2.4	...	...
No. 23	21.43	4.27	5.44	63.89	0.85*	1.50	56.4	18.9	2.1	16.6	2.6	...	...
No. 31	20.36	4.96	2.11	63.28	3.20*	2.23	60.1	13.0	9.6	6.4	3.8	...	...
No. 33	20.03	5.08	2.52	63.81	1.38*	2.31	63.2	9.8	9.2	7.7	3.9	...	...
No. 3L	21.39	1.88	5.08	65.31	1.76	2.32	73.7	5.7	...	9.0	3.9	3.6	...

[a] Corrections:
SiO_2 by subtracting ⅔ of the insoluble residue from the SiO_2 as determined.
Al_2O_3 by subtracting ⅓ of the insoluble residue, P_2O and TiO_2 from the Al_2O_3 as determined.
CaO by subtracting free CaO from the CaO as determined.
MgO (values marked with asterisk) by subtracting Mn_2O_3 from the MgO as determined.
MgO (other values) did not require correction since Mn_2O_3 was removed before the separation of MgO.

TABLE IV.—AVERAGE WEIGHT OF 10-IN. LEAN MORTAR BARS.

Cement	Plain Mortar	Air-Entrained Mortar
No. 11	393	...
No. 14	386	...
No. 15	394	...
No. 16	393	...
No. 2I	397	369
No. 2L	394	366
No. 2M	395	371
No. 2S	395	370
No. 21	396	368
No. 22	394	...
No. 23	394	...
No. 31	398	...
No. 33	395	...
No. 3L	398	...
No. 41	390	374
No. 43[a]	391	371
No. 43[b]	386	...
No. 43A	392	375
No. 5I	395	374
No. 5L	393	371
No. 5M	395	375
No. 5S	395	374
No. 51[a]	395	373
No. 51[b]	397	...
Average All Bars	394	372

[a] 1951 Tests.
[b] 1952 Tests.

Colorado State Highways
Lehigh Portland Cement Co.
Lone Star Cement Corp.
Louisville Cement Corp.
Marquette Cement Manufacturing Co.
National Bureau of Standards
Pennsylvania-Dixie Cement Corp.
Portland Cement Assn.
U.S. Bureau of Reclammation
Universal Atlas Cement Co.
Washington State Highways.
Waterways Experiment Station, Corps of Engineers, U.S. Army.

The numbers assigned to these laboratories do not correspond to the order in which they are here listed.

Chemical Composition of Cements:

The chemical composition of the cements as determined by the Portland Cement Assn. is given in Tables I, II, and III.

Mortar Bar Expansion:

The average weights of the lean mortar bars are listed in Table IV.

Four mortar bars were made with each cement, and laboratories reported per cent expansion calculated from length readings taken every 7 days, up to a total exposure of 84 days. The average per cent expansions reported by all laboratories are given in Table V for the plain mortar bars, and in Table VI for the mortar bars made with air-entrained cement. Individual laboratory averages for per cent expansion of the plain mortar bars at 28, 42, and 56 days, are given in Table VII.

TABLE V.—AVERAGE PER CENT EXPANSION—PLAIN MORTAR BARS.

Cement	Average Expansion at Various Times in Solution, per cent											
	7 days	14 days	21 days	28 days	35 days	42 days	49 days	56 days	63 days	70 days	77 days	84 days
No. 11	0.006	0.011	0.018	0.042	0.072	0.160	...	...	...	...	...	...
No. 14	0.006	0.009	0.013	0.017	0.020	0.023	0.026	0.031	0.035	0.042	0.052	0.059
No. 15	0.006	0.010	0.031	0.095	0.209	...	...	...	...	...	...	...
No. 16	0.006	0.010	0.014	0.018	0.025	0.035	0.045	0.065	0.096	0.094	0.136	...
No. 2I	0.007	0.010	0.014	0.016	0.018	0.019	0.023	0.024	0.026	0.031	0.034	0.039
No. 2L	0.008	0.011	0.015	0.017	0.018	0.020	0.021	0.023	0.023	0.025	0.026	0.028
No. 2M	0.008	0.011	0.014	0.016	0.018	0.021	0.022	0.023	0.024	0.026	0.028	0.029
No. 2S	0.009	0.014	0.018	0.021	0.023	0.025	0.028	0.028	0.030	0.032	0.034	0.036
No. 21	0.007	0.012	0.017	0.021	0.024	0.027	0.031	0.034	0.037	0.043	0.047	0.052
No. 22	0.009	0.014	0.018	0.022	0.026	0.030	0.034	0.039	0.046	0.053	0.063	0.066
No. 23	0.005	0.008	0.011	0.012	0.014	0.015	0.016	0.018	0.019	0.020	0.021	0.023
No. 31	0.006	0.010	0.021	0.064	0.151	...	...	...	...	...	...	...
No. 33	0.006	0.012	0.090	0.264	...	...	...	...	...	...	...	...
No. 3L	0.002	0.004	0.005	0.006	0.006	0.008	0.008	0.009	0.009	0.010	0.010	0.010
No. 41	0.007	0.014	0.019	0.023	0.026	0.029	0.032	0.033	0.036	0.038	0.041	0.044
No. 43[a]	0.007	0.012	0.019	0.024	0.031	0.051	0.069	0.086	0.067	0.066	0.077	0.088
No. 43[b]	0.007	0.012	0.018	0.025	0.033	0.041	0.050	0.058	0.062	0.071	0.082	0.093
No. 43A	0.009	0.013	0.018	0.019	0.021	0.023	0.025	0.025	0.027	0.029	0.031	0.034
No. 5I	0.005	0.008	0.012	0.013	0.013	0.015	0.016	0.017	0.018	0.019	0.020	0.022
No. 5L	0.007	0.008	0.012	0.013	0.014	0.016	0.017	0.017	0.018	0.020	0.021	0.023
No. 5M	0.008	0.012	0.016	0.017	0.019	0.021	0.021	0.022	0.023	0.024	0.025	0.026
No. 5S	0.008	0.012	0.016	0.018	0.018	0.021	0.022	0.024	0.025	0.025	0.026	0.028
No. 51[a]	0.006	0.009	0.011	0.014	0.015	0.016	0.018	0.018	0.020	0.021	0.022	0.024
No. 51[b]	0.005	0.008	0.010	0.013	0.014	0.015	0.016	0.018	0.020	0.021	0.022	0.023

[a] 1951 Tests.
[b] 1952 Tests.

TABLE VI.—AVERAGE PER CENT EXPANSION—AIR-ENTRAINED CEMENT MORTAR BARS.

Cement	Average Expansion at Various Times in Solution, per cent											
	7 days	14 days	21 days	28 days	35 days	43 days	49 days	56 days	63 days	70 days	77 days	84 days
No. 2I	0.004	0.006	0.008	0.009	0.010	0.012	0.012	0.013	0.014	0.017	0.018	0.020
No. 2L	0.005	0.008	0.010	0.011	0.012	0.012	0.012	0.013	0.015	0.016	0.017	0.019
No. 2M	0.007	0.009	0.011	0.011	0.014	0.015	0.014	0.016	0.016	0.019	0.020	0.021
No. 2S	0.006	0.010	0.012	0.014	0.017	0.018	0.019	0.020	0.021	0.023	0.024	0.026
No. 21	0.006	0.008	0.011	0.013	0.018	0.019	0.020	0.022	0.024	0.026	0.028	0.031
No. 41	0.008	0.012	0.017	0.019	0.022	0.024	0.025	0.028	0.030	0.032	0.034	0.036
No. 43	0.004	0.009	0.014	0.017	0.021	0.025	0.029	0.036	0.034	0.042	0.050	0.061
No. 43A	0.006	0.009	0.012	0.015	0.017	0.018	0.018	0.021	0.022	0.025	0.026	0.028
No. 5I	0.007	0.007	0.009	0.010	0.012	0.012	0.012	0.013	0.014	0.016	0.016	0.018
No. 5L	0.005	0.007	0.009	0.011	0.013	0.013	0.013	0.015	0.015	0.018	0.017	0.019
No. 5M	0.007	0.010	0.013	0.015	0.017	0.017	0.018	0.020	0.021	0.023	0.023	0.024
No. 5S	0.006	0.010	0.013	0.015	0.017	0.018	0.017	0.019	0.020	0.022	0.021	0.023
No. 51	0.004	0.006	0.009	0.009	0.013	0.013	0.013	0.015	0.015	0.017	0.017	0.019

Figure 1 is a plot of the data in Table V and Fig. 2 is a plot of the 28-day data in Table VII. Figures 3 to 6 further illustrate graphically the results obtained.

Sulfate Susceptibility:

Ten laboratories made the sulfate susceptability test, the results of which have been calculated both as sulfate recommended value (Table VIII), and per cent SO_3 combined (Table IX). These values are plotted in Figs. 7 and 8.

Discussion of Results:

It is seen that in the mortar bar tests, some cements show a marked increase in expan-

TABLE VII.—EXPANSION, INDIVIDUAL LABORATORY AVERAGES.

Cement No.	11	14	15	16	2I	2L	2M	2S	21	22	23	31	33	3L	41	43[a]	43[b]	43A	5I	5L	5M	5S	51[a]	51[b]
28-day Expansion, per cent																								
Lab. No. 1	0.059	0.016	0.213	0.016	0.017	0.019	0.011	0.017	0.020	0.019	0.009	0.109	0.980	0.002	0.023	0.026	0.023	0.020	0.009	0.007	0.014	0.014	0.010	0.008
No. 2	0.034	0.013	0.276	0.016	0.018	0.020	0.023	0.023	0.026	0.019	0.008	0.088	0.892	0.003	0.029	0.026	0.024	0.021	0.016	0.016	0.020	0.020	0.014	0.008
No. 3	0.063	0.019	0.105	0.025	...	...	...	...	...	0.014	0.001	0.035	0.088	−0.001	...	...	0.017	...	...	...	...	...	...	0.001
No. 4	0.025	0.011	0.081	0.019	0.023	0.025	0.021	0.030	0.028	0.023	0.016	0.031	0.041	0.005	0.029	0.031	0.027	0.023	0.018	0.018	0.021	0.025	0.019	0.016
No. 5	0.162	0.021	*	0.024	...	...	...	...	...	0.031	0.016	0.339	*	0.006	...	...	0.032	...	...	...	...	...	...	0.015
No. 6	0.020	0.015	0.046	0.017	0.008	0.008	0.004	0.013	0.014	0.017	0.009	0.019	0.056	0.005	0.014	0.017	0.021	0.015	0.009	0.007	0.011	0.013	0.008	0.013
No. 7	0.034	0.031	0.085	0.034	0.007	0.018	0.020	0.020	0.014	0.043	0.027	0.034	0.063	0.020	0.017	0.025	0.041	0.014	0.011	0.013	0.014	0.017	0.013	0.026
No. 8	0.048	0.020	0.239	0.020	0.022	0.019	0.023	0.018	0.029	0.025	0.012	0.076	0.896	0.008	0.020	0.028	0.037	0.021	0.014	0.017	0.022	0.022	0.020	0.017
No. 9	0.028	0.019	0.034	0.019	0.017	0.017	0.019	0.024	0.022	0.027	0.015	0.029	0.077	0.010	0.025	0.022	0.026	0.021	0.013	0.014	0.021	0.021	0.015	0.018
No. 10	...	...	...	...	0.020	0.020	0.010	0.020	0.020	...	...	...	...	...	0.020	0.030	...	0.020	0.020	0.020	0.010	0.020	0.020	...
No. 12	0.018	0.011	0.019	0.012	0.013	0.014	0.014	0.018	0.017	0.016	0.009	0.017	0.034	0.004	0.021	0.020	0.020	0.014	0.008	0.011	0.015	0.013	0.010	0.006
No. 13	0.012	0.009	0.012	0.007	0.017	0.018	0.020	0.024	0.022	0.017	0.015	0.014	0.010	0.006	0.026	0.025	0.018	0.020	0.015	0.015	0.021	0.021	0.014	0.011
No. 14	0.023	0.017	0.019	0.017	0.012	0.015	0.015	0.018	0.017	0.021	0.012	0.022	0.023	0.007	0.023	0.018	0.023	0.016	0.011	0.010	0.020	0.015	0.013	0.014
No. 15	0.014	0.014	0.010	0.010	0.013	0.015	0.023	0.030	0.026	0.019	0.012	0.013	0.011	0.002	0.029	0.028	0.013	0.026	0.015	0.019	0.023	0.025	0.015	0.010
No. 17	...	...	...	...	0.010	0.010	0.009	0.013	0.013	...	...	...	...	...	0.018	0.015	...	0.014	0.004	0.004	0.007	0.007	0.006	...
Average	0.042	0.017	0.095	0.018	0.016	0.017	0.016	0.021	0.021	0.022	0.012	0.064	0.264	0.006	0.023	0.024	0.025	0.019	0.013	0.013	0.017	0.018	0.014	0.013
42-day Expansion, per cent																								
Lab. No. 1	*	0.021	*	0.028	0.025	0.026	0.026	0.029	0.033	0.027	0.012	*	*	0.003	0.037	0.064	0.035	0.026	0.016	0.017	0.023	0.024	0.021	0.011
No. 2	0.362	0.018	*	0.024	0.021	0.022	0.026	0.026	0.032	0.023	0.009	*	*	0.005	0.034	0.034	0.030	0.025	0.018	0.019	0.023	0.024	0.017	0.010
No. 3	0.238	0.026	0.766	0.046	...	...	...	...	...	0.020	0.008	0.645	*	0.004	...	...	0.064	...	...	...	...	...	...	0.005
No. 4	0.084	0.020	*	0.029	0.025	0.026	0.021	0.033	0.032	0.034	0.020	0.085	*	0.009	0.030	0.038	0.049	0.026	0.018	0.020	0.021	0.025	0.020	0.019
No. 5	*	0.028	*	0.047	...	...	...	...	...	0.043	0.020	*	*	0.008	...	...	0.051	...	...	...	...	...	...	0.019
No. 6	0.073	0.020	0.283	0.026	0.011	0.011	0.008	0.017	0.020	0.023	0.011	0.082	0.564	0.006	0.019	0.021	0.025	0.015	0.009	0.007	0.012	0.013	0.009	0.016
No. 7	0.132	0.042	0.249	0.075	0.022	0.022	0.024	0.028	0.032	0.051	0.029	0.076	*	0.022	0.033	0.247	0.071	0.027	0.017	0.020	0.024	0.023	0.017	0.032
No. 8	0.457	0.029	*	0.046	0.020	0.020	0.028	0.023	0.030	0.034	0.016	0.791	*	0.010	0.027	0.034	0.059	0.031	0.018	0.018	0.026	0.023	0.021	0.015
No. 9	0.183	0.024	*	0.030	0.024	0.024	0.025	0.031	0.031	0.035	0.018	0.328	*	0.011	0.033	0.035	0.038	0.027	0.017	0.017	0.024	0.024	0.019	0.020
No. 10	...	...	...	...	0.020	0.020	0.020	0.020	0.020	...	...	...	...	...	0.020	0.040	...	0.020	0.020	0.020	0.020	0.020	0.020	...
No. 12	0.102	0.017	0.438	0.023	0.016	0.016	0.017	0.020	0.022	0.023	0.013	0.164	0.833	0.006	0.026	0.030	0.032	0.020	0.011	0.013	0.018	0.016	0.012	0.010
No. 13	0.018	0.011	0.032	0.013	0.018	0.017	0.019	0.025	0.024	0.023	0.016	0.031	0.046	0.007	0.028	0.032	0.026	0.021	0.013	0.014	0.019	0.020	0.013	0.013
No. 14	0.079	0.022	0.018	0.023	0.017	0.019	0.019	0.022	0.024	0.027	0.015	0.089	0.074	0.008	0.029	0.031	0.031	0.022	0.014	0.014	0.022	0.020	0.016	0.016
No. 15	0.031	0.018	0.041	0.017	0.018	0.017	0.026	0.033	0.036	0.027	0.012	0.048	0.083	0.002	0.037	0.035	0.017	0.029	0.019	0.021	0.025	0.027	0.017	0.011
No. 17	...	...	...	...	0.014	0.014	0.013	0.018	0.021	...	...	...	...	...	0.024	0.024	...	0.016	0.004	0.006	0.010	0.012	0.006	...
Average	0.160	0.023	0.275	0.033	0.019	0.020	0.021	0.025	0.027	0.030	0.015	0.234	0.320	0.008	0.029	0.051	0.041	0.023	0.015	0.016	0.021	0.021	0.016	0.015
56-day Expansion, per cent																								
Lab. No. 1	*	0.026	*	0.055	0.037	0.037	0.031	0.035	0.044	0.035	0.014	*	*	0.004	0.044	0.137	0.049	0.036	0.024	0.023	0.030	0.030	0.026	0.013
No. 2	*	0.018	*	0.036	0.027	0.024	0.029	0.030	0.038	0.027	0.011	*	*	0.006	0.038	0.041	0.034	0.028	0.020	0.021	0.028	0.027	0.020	0.011
No. 3	*	0.057	*	0.079	...	...	...	...	...	0.031	0.011	*	*	0.005	...	...	0.115	...	...	...	...	...	...	0.010
No. 4	0.287	0.022	*	0.048	0.030	0.025	0.021	0.034	0.034	0.040	0.021	0.643	*	0.010	0.034	0.028	0.070	0.024	0.017	0.018	0.020	0.024	0.018	0.021
No. 5	*	0.036	*	0.103	...	...	...	...	...	0.061	0.023	*	*	0.009	...	...	0.072	...	...	...	...	...	...	0.021
No. 6	0.293	0.023	*	0.037	0.014	0.017	0.009	0.020	0.024	0.026	0.012	*	*	0.006	0.024	0.026	0.034	0.018	0.008	0.008	0.018	0.018	0.015	0.017
No. 7	0.353	0.060	*	0.201	0.034	0.026	0.031	0.032	0.045	0.070	0.031	0.384	*	0.024	0.041	0.477	0.097	0.029	0.021	0.023	0.027	0.027	0.022	0.034
No. 8	*	0.035	*	0.102	0.023	0.023	0.027	0.034	0.038	0.046	0.016	*	*	0.008	0.030	0.038	0.086	0.029	0.024	0.019	0.028	0.027	0.030	0.016
No. 9	*	0.034	*	0.058	0.030	0.030	0.030	0.038	0.039	0.047	0.024	*	*	0.013	0.040	0.050	0.050	0.034	0.021	0.022	0.028	0.027	0.022	0.026
No. 10	...	...	...	...	0.020	0.020	0.010	0.020	0.020	...	...	...	...	...	0.020	0.070	...	0.020	0.010	0.010	0.010	0.020	0.010	...
No. 12	0.699	0.025	*	0.041	0.021	0.017	0.020	0.025	0.028	0.028	0.016	0.730	*	0.007	0.031	0.043	0.050	0.022	0.013	0.016	0.020	0.018	0.014	0.014
No. 13	0.052	0.019	0.437	0.026	0.021	0.020	0.023	0.028	0.028	0.031	0.023	0.155	0.453	0.011	0.032	0.042	0.036	0.023	0.015	0.016	0.020	0.022	0.014	0.018
No. 14	0.676	0.028	*	0.036	0.022	0.023	0.024	0.027	0.031	0.035	0.016	*	*	0.009	0.033	0.049	0.038	0.024	0.018	0.017	0.024	0.022	0.018	0.018
No. 15	0.118	0.023	*	0.025	0.022	0.022	0.028	0.037	0.046	0.030	0.012	*	0.256	0.002	0.044	0.049	0.024	0.037	0.021	0.025	0.029	0.032	0.022	0.011
No. 17	...	...	...	...	0.016	0.014	0.013	0.019	0.025	...	...	...	...	...	0.026	0.039	...	0.016	0.003	0.005	0.009	0.012	0.007	...
Average	0.354	0.031	0.437	0.065	0.024	0.023	0.023	0.028	0.034	0.039	0.018	0.478	0.354	0.009	0.033	0.086	0.058	0.026	0.017	0.017	0.022	0.024	0.018	0.018

* Measurements discontinued. [a] 1951 Tesst. [b] 1952 Tests.

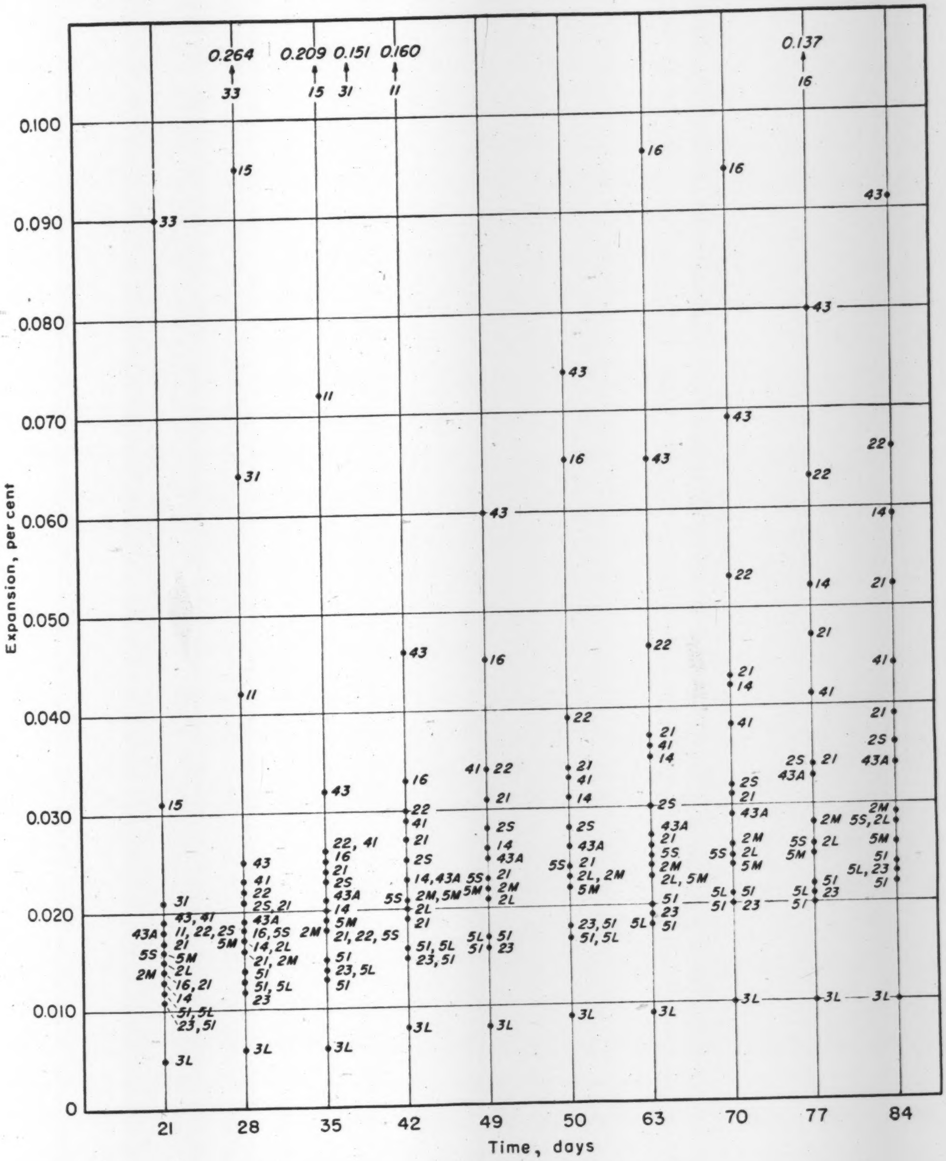

Fig. 1.—Average Expansion All Laboratories.

sion after immersion for 21 days, while others have not expanded appreciably even after immersion for 84 days.

The grouping of the cements in Table X is based on the expansion of 28 days and the sulfate reaction value according to type of cement. Type II, type IV and type V cements show consistently low expansion at 28 days, varying from 0.013 to 0.025 per cent. In the type I cements the expansion varies from 0.017 to 0.095 per cent, the average expansion being 2 to 3 times as great as the average for type II, type IV, and type V. Of the type III cements, two showed marked expansion; the third, No. 3L, showed the lowest expansion of all the cements studied.

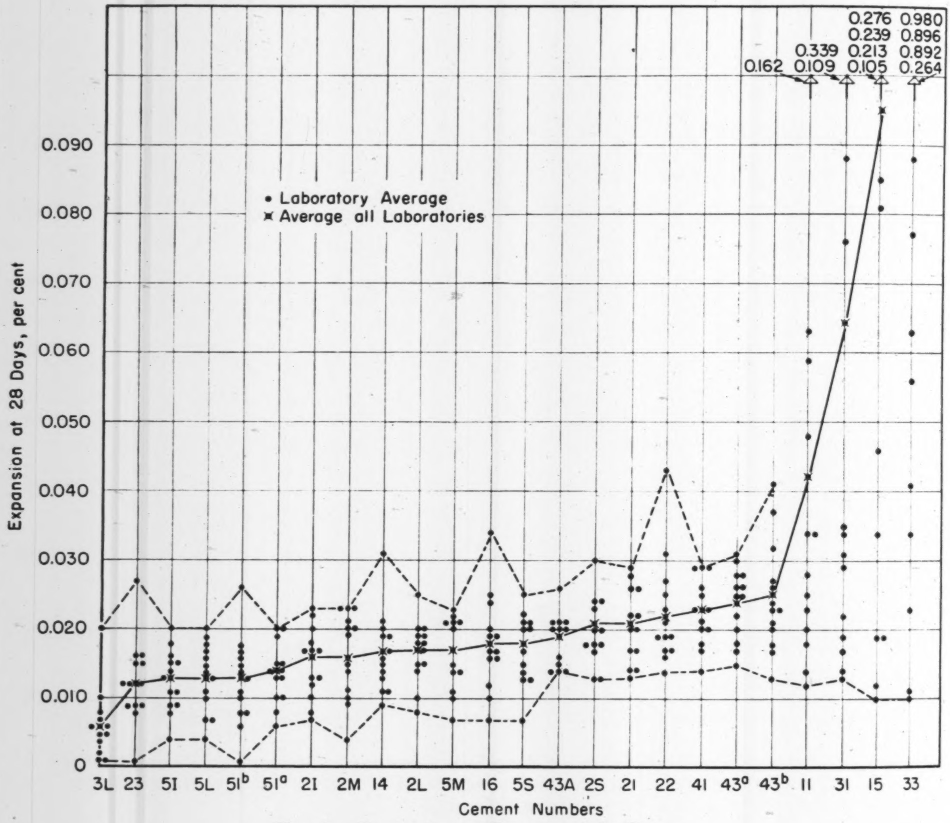

Fig. 2.—Expansion at Twenty-eight Days.

Taylor and Bogue[6] group cements according to sulfate reaction value as follows:

Sulfate Reaction Value	Sulfate Resistance
Below 50..........	Relatively resistant, the lower the value, the greater the resistance.
50 to 65..........	Doubtful.
Above 65..........	Relatively nonresistant, the higher the value, the lower the resistance.

Comparison of Tables V and VI shows that air-entrainment retards expansion, but does not completely inhibit the reaction which causes the increase in volume of mortar. It is unfortunate that the more rapidly expanding cements were not included in the series with air-entraining agent. The results with those cements might have been more conclusive.

From Table IV it is seen that the bars made with air-entrained cements weighed about 6 per cent less than the plain bars.

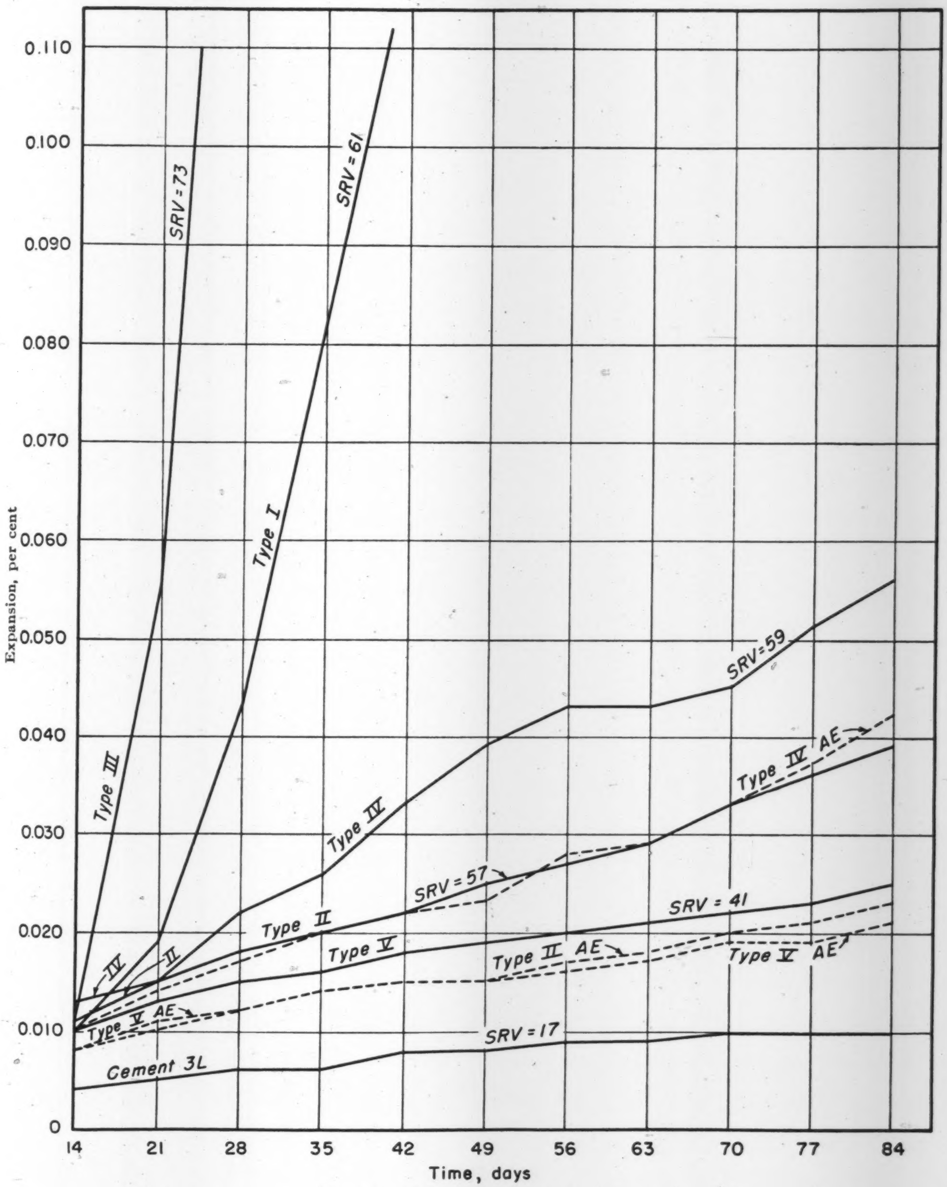

Fig. 3.—Expansion by Types.

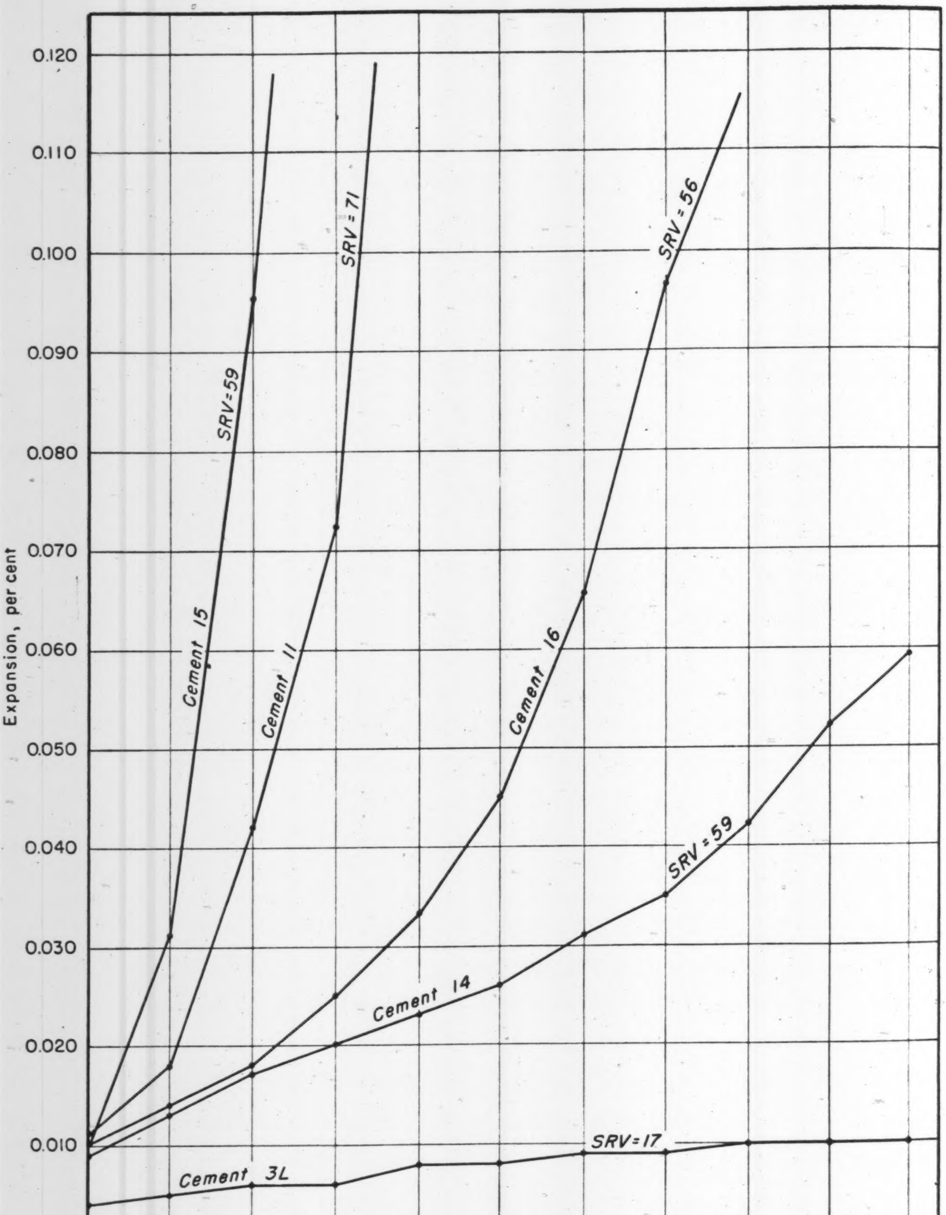

Fig. 4.—Expansion Type I Cements.

However, the weight of bars does not seem to have any significance, and it has been suggested that weighing the specimens might be eliminated from the test procedure.

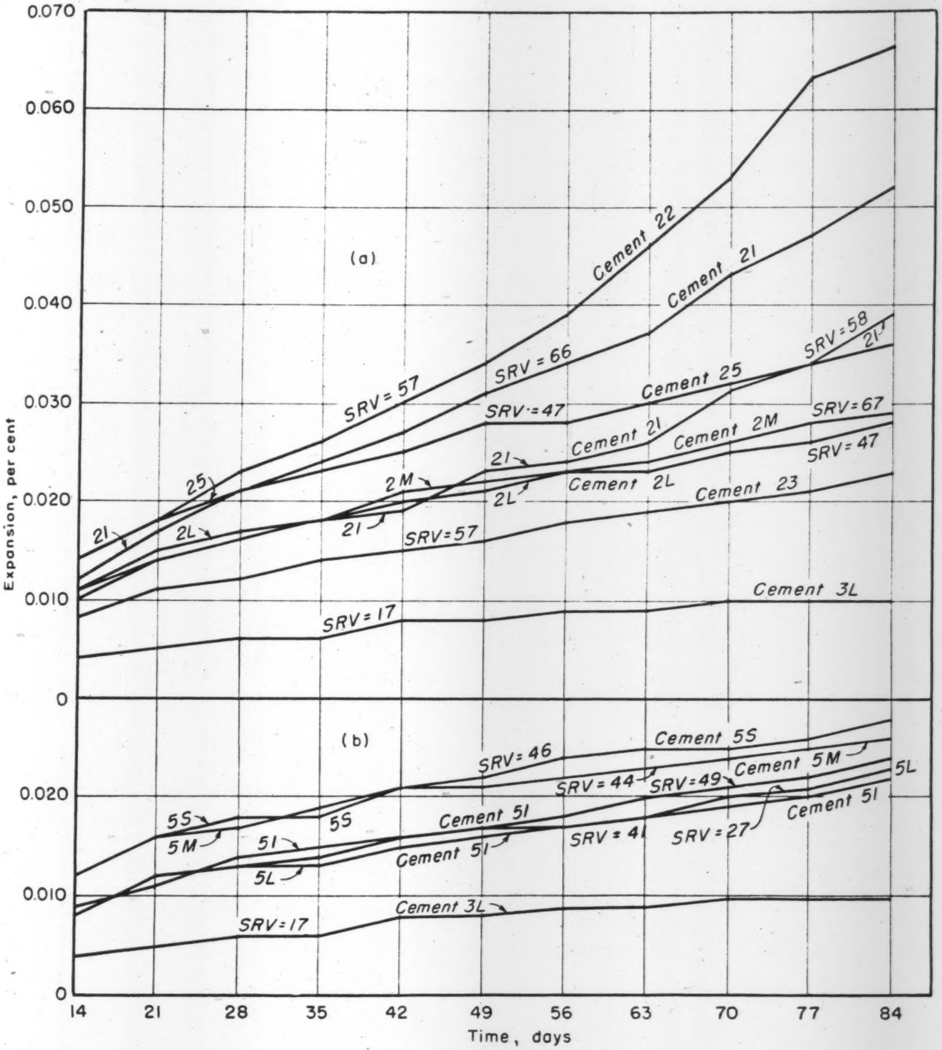

Fig. 5.—Expansion Types II and V Cements, (*a*) Type II Cement and (*b*) Type V Cement.

Reproducibility:

In general the test values reported by individual laboratories showed good reproducibility, but some laboratories had difficulty. A comparison of laboratory averages shows that there is general agreement, but there are a number of rather marked discrepancies. This applies to both proposed test methods.

Further study of these methods may uncover the reasons for these variations and lead to modification and refinements in the

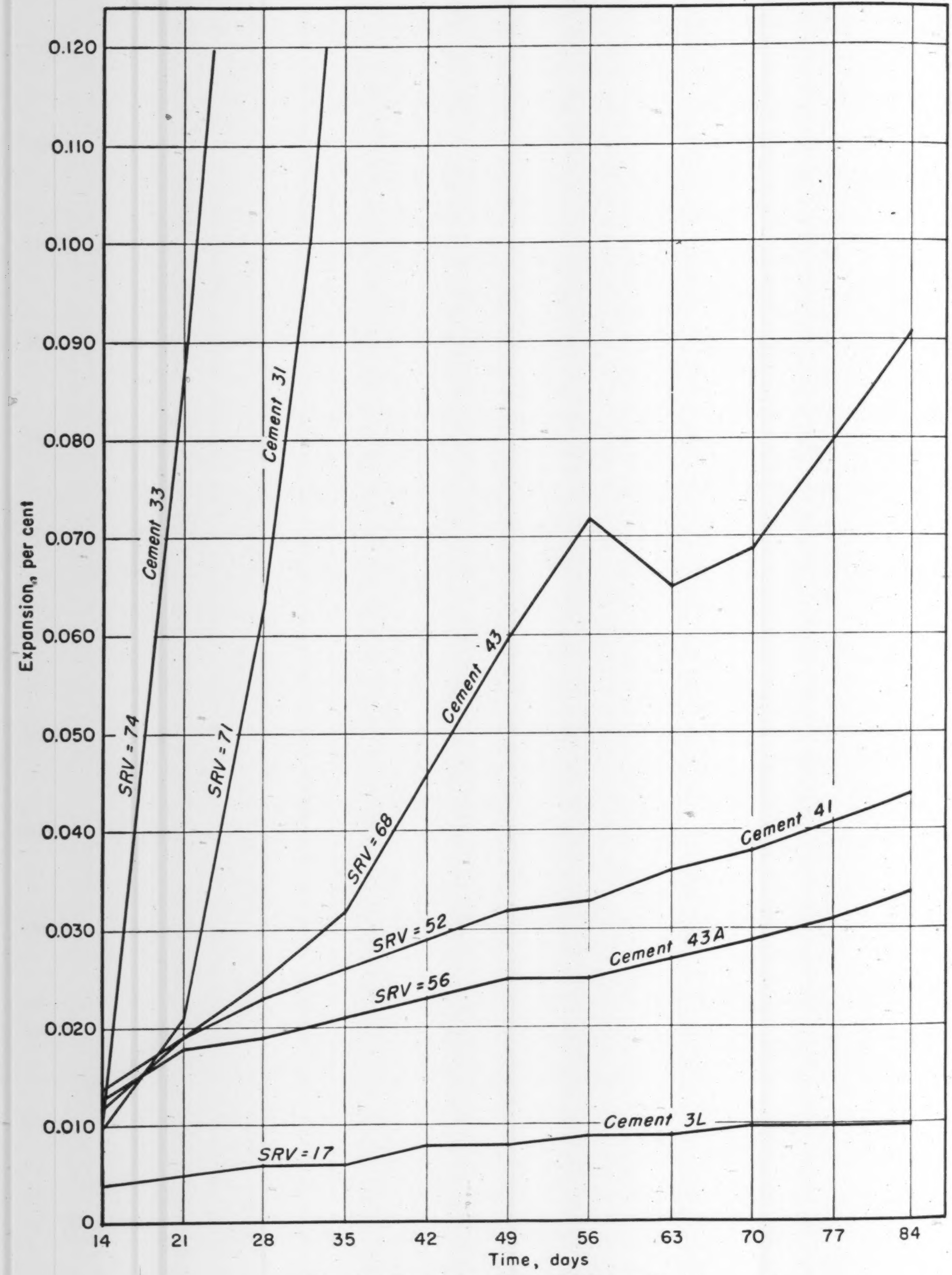

Fig. 6.—Expansion Type IV Cements.

TABLE VIII.—SULFATE SUSCEPTIBILITY—SULFATE REACTION VALUES.

Cement	Lab. No. 1	Lab. No. 2	Lab. No. 3	Lab. No. 5	Lab. No. 6	Lab. No. 7	Lab. No. 8	Lab. No. 9	Lab. No. 14	Lab. No. 15	Average
No. 11	67	69	67	74	78	85	70	43	86	...	71
No. 14	55	51	55	60	55	75	56	56	71	...	59
No. 15	56	61	48	61	48	60	56	64	79	...	59
No. 16	50	56	49	56	52	60	54	62	68	...	56
No. 2I	56	59	58	56	64	...	57	54	56	59	58
No. 2L	43	47	44	47	56	...	45	42	52	44	47
No. 2M	63	71	68	69	68	...	70	56	70	68	67
No. 2S	46	50	47	43	54	...	43	45	45	51	47
No. 21	62	68	63	64	66	...	68	68	70	68	66
No. 22	49	59	48	50	71	58	52	58	67	...	57
No. 23	50	54	56	61	65	62	63	44	60	...	57
No. 31	66	70	66	67	83	93	64	45	82	...	71
No. 33	64	69	66	76	92	87	71	53	91	...	74
No. 3L	11	17	12	20	20	23	15	(87)*	19	...	17
No. 41	51	57	49	53	56	...	57	46	53	50	52
No. 43[a]	66	71	74	67	62	...	70	61	76	63	68
No. 43[b]	56	...	60	63	88	80	72	45	76	...	68
No. 43A	55	58	55	57	54	...	57	53	57	60	56
No. 5I	40	45	41	43	36	...	40	39	42	41	41
No. 5L	26	31	32	29	20	...	21	25	28	29	27
No. 5M	46	52	44	50	21	...	50	41	49	44	44
No. 5S	43	50	45	52	47	...	45	49	40	39	46
No. 51[a]	49	50	47	46	46	...	50	51	49	47	48
No. 51[b]	40	...	51	48	42	54	55	54	51	...	49

[a] 1951 tests.
[b] 1952 tests.
* Not included in average.

TABLE IX.—SULFATE SUSCEPTIBILITY—PER CENT SO$_3$ COMBINED.

Cement	Lab. No. 1	Lab. No. 2	Lab. No. 3	Lab. No. 5	Lab. No. 6	Lab. No. 7	Lab. No. 8	Lab. No. 9	Lab. No. 14	Lab. No. 15	Average
No. 11	0.965	0.997	0.965	1.177	1.240	1.351	1.113	0.682	1.357	...	1.129
No. 14	0.951	0.882	0.951	1.038	0.951	1.300	0.969	0.969	1.228	...	1.021
No. 15	1.075	1.171	0.922	1.171	0.922	1.152	1.075	1.229	1.537	...	1.133
No. 16	0.855	0.958	0.838	0.958	0.889	1.026	0.923	1.060	1.163	...	0.958
No. 2I	0.946	0.997	0.980	0.946	1.082	...	0.963	0.913	0.946	0.997	0.980
No. 2L	0.718	0.785	0.735	0.785	0.935	...	0.752	0.701	0.868	0.735	0.785
No. 2M	0.932	1.051	1.006	1.021	1.006	...	1.036	0.829	1.036	1.006	0.992
No. 2S	0.800	0.870	0.818	0.748	0.940	...	0.748	0.783	0.783	0.887	0.818
No. 21	0.769	0.843	0.781	0.794	0.818	...	0.843	0.843	0.868	0.843	0.818
No. 22	0.691	0.832	0.677	0.705	1.001	0.818	0.733	0.818	0.945	...	0.804
No. 23	0.750	0.810	0.840	0.915	0.975	0.930	0.945	0.660	0.900	...	0.855
No. 31	1.472	1.561	1.472	1.494	1.854	2.074	1.427	1.004	1.829	...	1.583
No. 33	1.478	1.594	1.525	1.756	2.125	2.010	1.640	1.224	2.102	...	1.709
No. 3L	0.255	0.394	0.278	0.464	0.464	0.534	0.348	(2.018)*	0.441	...	0.397
No. 41	1.010	1.129	0.970	1.049	1.109	...	1.129	0.911	1.049	0.990	1.030
No. 43[a]	1.300	1.399	1.458	1.320	1.221	...	1.379	1.202	1.491	1.241	1.340
No. 43[b]	1.103	...	1.182	1.241	1.734	1.576	1.318	0.887	1.491	...	1.340
No. 43A	1.029	1.085	1.029	1.066	1.010	...	1.066	0.991	1.066	1.122	1.047
No. 5I	0.672	0.736	0.689	0.722	0.605	...	0.672	0.655	0.706	0.689	0.689
No. 5L	0.452	0.539	0.557	0.505	0.348	...	0.355	0.435	0.487	0.505	0.470
No. 5M	0.800	0.905	0.766	0.870	0.365	...	0.870	0.713	0.853	0.766	0.766
No. 5S	0.628	0.730	0.657	0.759	0.686	...	0.657	0.715	0.584	0.569	0.672
No. 51[a]	0.686	0.700	0.658	0.644	0.644	...	0.700	0.714	0.686	0.658	0.672
No. 51[b]	0.560	...	0.714	0.672	0.588	0.756	0.770	0.756	0.714	...	0.686

[a] 1951 series.
[b] 1952 series.
* Not included in average.

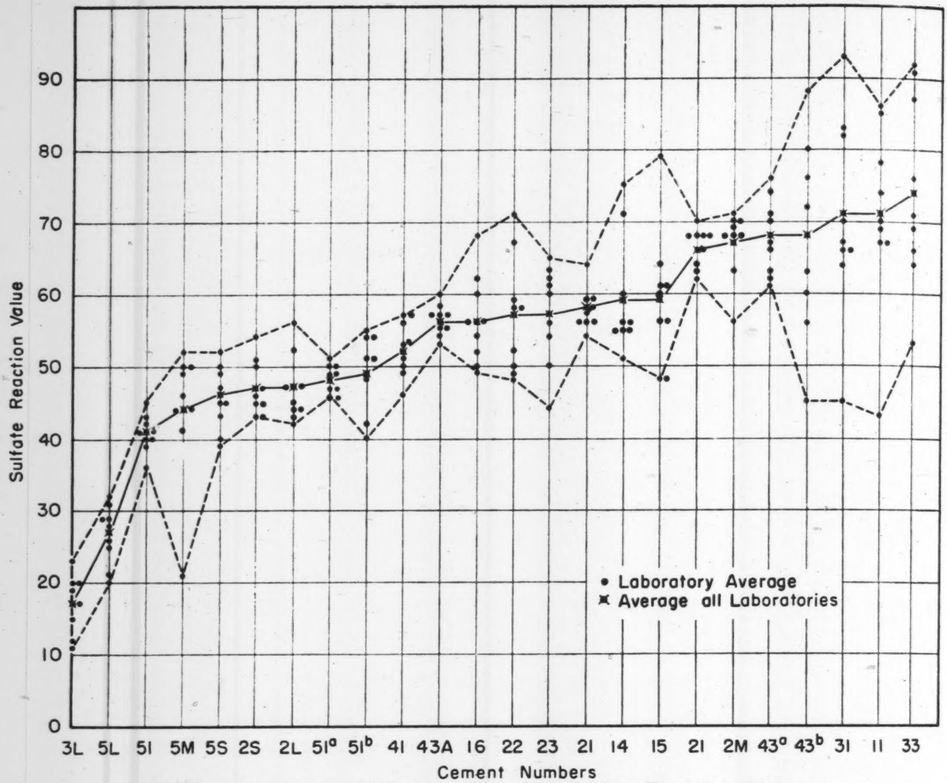

Fig. 7.—Comparison of Cements Based on Sulfate Reactions Value.

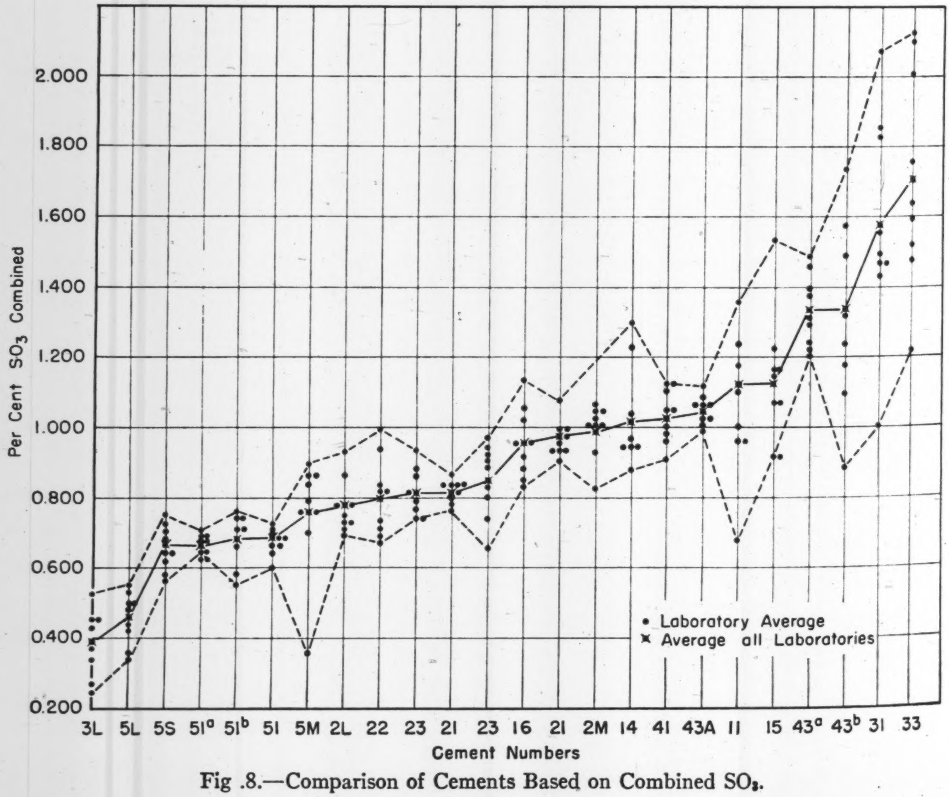

Fig .8.—Comparison of Cements Based on Combined SO_3.

procedures which will improve reproducibility and correlation.

CONCLUSIONS

1. The two proposed test methods definitely detect cements low in sulfate resistance.

2. With the mortar bar expansion test, immersion for 28 days is sufficient for detecting cements of low resistance.

3. While the correlation between the results of the two methods is not good, there is some indication that the sulfate reaction value reveals differences (and similarities) in cement properties which become evident in the bar test only after prolonged immersion. This is only a tentative statement, which in some cases may not be true.

4. It is recommended that the two proposed methods of test be used by all those interested in studying the sulfate resistance of cements so that a larger volume of data may become available for developing a test procedure suitable for specification purposes.

Acknowledgments:

The cooperation of all those who participated in the test program is grateful acknowledged. Thanks are due the Portland Cement Assn. for the cement analyses and for the preparation and distribution of the cement samples. The assistance and advice of Mr. William Lerch have been most helpful.

TABLE X.—EXPANSION AT 28 DAYS AND SULFATE SUSCEPTIBILITY.

Cement	Expansion, per cent	Sulfate Reaction Values	Percentage SO_3 Combined
TYPE I			
No. 14	0.017	59	1.021
No. 16	0.018	57	0.958
No. 11	0.042	71	1.129
No. 15	0.095	59	1.133
Average	0.043	61	1.060
TYPE II			
No. 23	0.012	57	0.855
No. 2I	0.016	58	0.980
No. 2M	0.016	67	0.992
No. 2L	0.017	47	0.785
No. 2S	0.021	47	0.818
No. 21	0.021	66	0.818
No. 22	0.022	57	0.804
Average	0.018	57	0.865
TYPE III			
No. 31	0.064	71	1.583
No. 33	0.264	74	1.709
Average	0.164	73	1.646
No. 3L	0.006	17	0.397
TYPE IV			
No. 43A	0.019	56	1.047
No. 41	0.023	52	1.030
No. 43	0.025	68	1.340
Average	0.022	59	1.139
TYPE V			
No. 5I	0.013	41	0.689
No. 5L	0.013	27	0.470
No. 51	0.014	49	0.679
No. 5M	0.017	44	0.766
No. 5S	0.018	46	0.672
Average	0.015	41	0.655

APPENDIX A

A Lean Mortar Bar Expansion Test for Sulfate Resistance of Portland Cements

Scope:

1. This method is intended for determining the sulfate resistance of portland cement by measuring the expansion of lean mortar bars immersed in sodium sulfate solution.

Apparatus:

2. (*a*) The scales, weights, sieves, glass graduates, mixing bowl, and tamper shall be as described in ASTM Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 - 49).[7]

(*b*) The flow table and mold shall be as described in ASTM Tentative Spec. for Flow Table for Use in Tests of Hydraulic Cements (C 230 - 49 T).[8]

(*c*) The specimen molds and length comparator shall be as described in ASTM Method of Test for Autoclave Expansion of Portland Cement (C 151 - 49).[9]

Sodium Sulfate Solution:

3. The solution used for immersing the mortar bars shall be a 5.0 per cent (0.352 molar) aqueous solution of C.P. anhydrous sodium sulfate, Na_2SO_4.

Temperature and Humidity:

4. (*a*) The temperature of the molding room and dry materials shall be maintained at not less than 20C (68 F) and not more than 27.5 C (81.5 F). The temperature of the mixing water and of the moist closet or moist room shall not vary from 23 C (73.4 F) by more than 1.7 C (3 F).

(*b*) The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 90 per cent.

Graded Standard Sand:

5. The graded standard Ottawa sand shall be as described in Section 4 of ASTM Method C 109 - 49.[7]

Preparation of Specimen Molds:

6. The specimen molds shall be lubricated with a light coating of lard oil.

Number of Specimens:

7. Two bars shall be made from each of two batches made on different days, or a total of four bars for each composition. The bars shall be provided with stainless steel gage points for length measurements.

Proportioning Consistency and Mixing of Mortar:

8. (*a*) The proportions of the standard sand mortar shall be 1 part of cement to 4 parts of graded standard sand by weight. The quantities of dry materials to be mixed at one time, for the preparation of two bars, shall be 300 g of cement and 1200 g of standard sand. The amount of mixing water, measured in millimeters, shall be such as to produce a flow of 100 to 115 as determined in Section 9 of ASTM Method C 109 - 49[7] and shall be expressed as percentage by weight of cement.

(*b*) Mixing shall be done in a bowl (Section 2 (*a*) by vigorous and continuous stirring, squeezing, and kneading with one hand which shall be protected by a snug-fitting rubber glove. The materials for a batch shall be introduced in the following manner:

(*1*) Place the water in the bowl, which has just been wiped with a damp cloth or damp sponge.

(*2*) Add the cement to the water and mix for 30 sec.

(*3*) Add approximately one-half of the testing sand, mix for 30 secs, and

(*4*) Add the remainder of the sand and mix for $1\frac{1}{2}$ min.

Molding the Bars:

9. Immediately following completion of the flow test, the mortar from the flow mold shall be returned to the mixing bowl and the entire

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[7] 1949 Book of ASTM Standards, Part 3, p. 92.

[8] *Ibid*, p. 25.

[9] *Ibid*, p. 35.

batch shall be given a 15-sec mixing with one hand protected with a rubber glove, after which the glove shall be freed of adhering mortar. A layer of mortar about ½ in. in thickness shall then be placed in each mold compartment. The tamper shall be the same as that described in ASTM C 109 – 49. The area around each reference plug shall be tamped five times with the end of the tamper to compact the mortar under and around the plug. In this operation the tamper shall be held to form approximately a 30-deg angle with the top of the mold and the movement of the tamping shall be directed toward the end of the mold. The mortar shall then be tamped 50 times, 25 times in each direction, with the flat end of the tamper. The tamper shall be held in position so the 1-in. edge is at right angles to the length of the mold. When the tamping of the first layer in each compartment is completed the mortar remaining in the mixing bowl shall be turned over with the gloved hand. The molds shall then be filled heaping full and again tamped 50 times, 25 times in each direction, with the flat end of the tamper. On completion of the tamping, the tops of the specimens should extend slightly above the tops of the molds. The mortar which has been forced out onto the tops of the molds shall be brought in with a trowel and the bars smoothed off by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each bar at right angles to the length of the mold. The mortar shall then be cut off to a plane surface flush with the top of the mold by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the top of the mold.

Curing:

10. The specimens shall be cured in the molds stored in the moist closet for 46 to 48 hr. Upon removal from the molds the bars shall be brushed lightly to remove loose material and any excess oil. They shall then be weighed, properly identified and stored in water at 23 ± 1.7 C (73.4 ± 3 F) for five days, or a total of 7 days preliminary curing.

Storage:

11. When the bars are 7 days old they shall be measured and stored in a 5.0 per cent (0.352M) solution of C.P. anhydrous sodium sulfate in metal or glass containers. The solution shall be maintained at a temperature of 23 ± 1.7 C (73.4 ± 3 F). The ratio of the volume of the bars to the volume of solution shall be 1 to 4 throughout the test. The bars shall be stored standing on end completely immersed in the sodium sulfate. A rubber grommet shall be placed over the end of the gage points or other means provided to prevent the wear or abrasion of the points. The metal or glass containers shall be covered to prevent evaporation and if necessary the original solution shall be maintained by the occasional addition of water. The solution shall not be renewed during the course of the tests.

Length Measurements:

12 (*a*) The bars shall be allowed to drain momentarily, after removal from the solution, before measuring. If more than one bar is removed from the container at one time, they shall be covered with a damp cloth to prevent evaporation.

(*b*) The first length measurement shall be be made at the end of the curing period, that is, when the specimens are 7 days old. The specimens shall then be measured every 7 days until they reach an expansion of 0.10 per cent. With larger expansions, the specimens warp and crack so the measured expansions have little if any quantitative significance. It will not be necessary to weigh the specimens, except to obtain the initial weight when they are removed from the molds as described above.

Calculation:

13. The percentage expansion at each age of test shall be calculated and recorded as the per cent of change in length calculated on the basis of the length at seven days, that is, at the time the specimens are first immersed in the sodium sulfate solution.

APPENDIX B

A SULFATE SUSCEPTIBILITY TEST FOR PORTLAND CEMENTS

Scope:

1. This method is intended for determining the sulfate resistance of portland cement by measuring the amount of the dissolved SO_3 rendered insoluble when the cement is shaken with lime water.

Apparatus:

2. (*a*) A 100-ml graduated cylinder with a capacity of 115–130 ml, and so designed that it can be fitted with a rubber stopper.

(*b*) A 100-ml pipette.

(*c*) A rotary shaker which operates at 60 rpm and is so designed that no cylinder is more than 6 in. from the hub.

Solution:

3. A saturated solution of lime water, $Ca(OH)_2$.

Temperature:

4. The temperature of the solution and the room in which the shaker operates shall be maintained at 23 C (73.4 F) ± 1.7 C (3 F).

Procedure:

5. (*a*) The SO_3 content of the cement shall be first determined in accordance with ASTM Standard Methods of Chemical Analysis of Portland Cement (C 114 – 47).[10]

(*b*) About 30 g of standard Ottawa sand, or some similar silica sand, shall be placed in a dry 100-ml graduated cylinder, and a blank determination shall be made with each lot of sand employed.

(*c*) A sample of cement shall be weighed out equal in grams to 5.4 divided by the per cent of SO_3 in the cement. This sample shall be placed in the cylinder with 30 g of the standard Ottawa or similar sand; 100 ml of saturated lime water shall be measured in a 100-ml pipette and added rapidly to the cylinder by inverting the pipette. A clean rubber stopper shall be inserted and the mixture at once shaken vigorously by hand. The cylinder shall then be fastened to a rotary shaker and the shaking continued for 6 hr from the time of the addition of the lime water.

(*d*) Just before the end of the 6-hr reaction period, a 9-cm. No. 42 filter paper (or a comparable paper) shall be inserted in a Buchner funnel and moistened with distilled water. Suction shall then be applied and the contents of the cylinder poured into the funnel. The cylinder shall be washed with 50–60 ml of distilled water and the washings poured into the funnel. This step shall be repeated once.

(*e*) The filtrate shall be transferred to a 600-ml beaker and the filtrate flask twice washed with 50–60 ml of distilled water and the washings added to the filtrate. The volume shall then be made up to about 350 ml, 5 ml of concentrated HCl shall be added, and the weight of the SO_3 shall be determined by precipitation with $BaCl_2$ solution in accordance with the standard procedure in Standard Methods C 114 – 47.

(*f*) After the amount of SO_3 remaining in the solution is determined, that value shall be subtracted from the amount of SO_3 that was present in the sample of the cement taken. This difference is assumed to be the quantity of SO_3 that has reacted to form calcium sulfoaluminate during the period of the test. This shall be calculated as a percentage of SO_3 originally present in the cement and shall be designated as the "sulfate reaction value." The sulfate reaction value shall be reported to the nearest whole number.

(*g*) The test shall be run in triplicate. Each value shall be reported and also the average for each cement. Sulfate reaction values differing by more than 3 points from the average of all tests shall not be considered in reporting the average value.

(*h*) Alternatively, the sulfate susceptibility may be expressed directly as the "per cent SO_3 combined." This is the difference obtained in (*f*) above by subtracting from the SO_3 present in the cement the amount of SO_3 remaining in the solution after shaking for 6 hr.

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[10] 1949 Book of ASTM Standards, Part 3, p. 38.

REPORT OF COMMITTEE C-2

ON

MAGNESIUM OXYCHLORIDE AND OXYSULFATE CEMENTS*

Committee C-2 on Magnesium Oxychloride and Oxysulfate Cements met once during the year, at the 1951 Annua lMeeting, on June 21, 1951 in Atlantic City, N. J.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. S. Wells.
Vice-Chairman, Dean Hubbell.
Secretary, J. B. James.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1951 Annual Meeting, Committee C-2 presented to the Society, through the Administrative Committee on Standards, the following recommendations:

Tentative Specifications for:

Magnesium Chloride (C 276 – 51 T),
Magnesium Sulfate, Technical Grade (C 277 – 51 T), and
Oxychloride Magnesia (C 275 – 51 T).

These recommendations were accepted by the Standards Committee, September 12, 1951, and the new tentatives appear in the 1951 Supplement to Book of ASTM Standards, Part 3.

Adoption of Tentatives as Standard

Committee C-2 recommends that the following fourteen methods[1] be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Methods of:

Chemical Analysis of Magnesium Sulfate, Technical Grade (C 244 – 50 T),
Chemical Analysis of Magnesium Chloride (C 245 – 50 T),
Physical Testing of Magnesia for Magnesium Oxychloride Cement (C 246 – 50 T),
Test for Ignition Loss and Active Calcium Oxide in Magnesium Oxide for Use in Magnesium Oxychloride Cements (C 247 – 50 T),
Test for Bulk Density of Magnesium Oxychloride Cements (C 248 – 50 T),
Slump Test for Field Consistency of Magnesium Oxychloride Cements (C 249 – 50 T),
Mixing Magnesium Oxychloride Cement Compositions with Gauging Solution (for Preparation of Specimens for Laboratory tests) (C 251 – 50 T),
Test for Linear Contraction of Magnesium Oxychloride Cements (C 252 – 50 T),
Test for Linear Change of Magnesium Oxychloride Cements (C 253 – 50 T),
Test for Setting Time of Magnesium Oxychloride Cements (C 254 – 50 T),
Test for Consistency of Magnesium Oxychloride Cements by the Flow Table (C 255 – 50 T),
Test for Flexural Strength of Magnesium Oxychloride Cements (Using Simple Bar with Two-Point or Single-Point Loading) (C 256 – 50 T), and
Test for Compressive Strength of Magnesium Oxychloride Cements (C 257 – 50 T).

Tentative Specifications and Method for:

Field Determination of Specific Gravity of Gauging Solutions for Magnesium Oxychloride Cements (C 250 – 50 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1951 Supplement to Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot vote of the committee, which consists of 19 members; 18 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. S. WELLS,
Chairman.

W. J. RILEY,
Secretary pro tem.

REPORT OF COMMITTEE C-3

ON

CHEMICAL-RESISTANT MORTARS*

Committee C-3 on Chemical-Resistant Mortars held two meetings during the year: in Atlantic City, N. J., June 22, 1951, in connection with the 1951 Annual Meeting of the Society, and on March 12, 1952, at ASTM Headquarters, Philadelphia, Pa.

At the present time there are 22 members on the committee, of whom 10 are classified as producers, 6 as consumers, and 6 as general interest members. There are also 5 consulting members. During the year a resignation was received from G. T. Haddock. R. Neuhaus, representing Nukem Products Co., was accepted as a new member, and Mr. Griffiths of Semtex Corp., London, England, was accepted as a consulting member.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Beaumont Thomas.

Vice-Chairman, C. R. Payne.

Secretary, J. R. Allen.

Members-at-large of Executive Subcommittee, F. H. Buckley, H. B. Staley, and F. O. Anderegg.

NEW TENTATIVE

The committee recommends for publication as tentative the specifications for Sulfur Mortars as appended hereto.[1]

The recommendation appearing in this report has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Silicate Mortars (W. Stericker, chairman) reports that proposed specifications including test methods for air-dry silicate mortars have been completed and after review will be submitted to the committee for balloting preparatory to presentation to the Society.

Subcommittee VII on Working and Setting Times (R. B. Seymour, chairman) reports completion of the investigational work and, subject to the decision of the committee on method of presentation and inclusiveness of the test procedures, will be able to submit a proposed method during the ensuing year.

Subcommittee VIII on Bond Strength (J. R. Allen, chairman).—This Subcommittee was established to investigate methods for the determination of bond strength. Several different procedures have been tried out. The most promising method employs a sample consisting of two brick with the flat surfaces symmetrically crossed at right angles and with the two interfaces joined by a mortar. The joint is tested in tension with a special cross head based on the principle of a universal joint. This arrangement permits self-alignment during application of the load and eliminates torque and bending of the joint. Numerous tests have been made employing this method to determine the bond strength developed between acid brick and representative chemical-set silicate cements and resin cements. Data indicate that very promising results can be obtained which yield a variation in the range ±10 to 15 per cent. This is an acceptable variation for a test of this type, and with additional work it is believed that this procedure can be developed as a satisfactory method for the determination of bond strength.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

The method and the results obtained to date have been submitted to the committee for consideration. At the same time, it is being arranged for several organizations to make duplicate tests to confirm the results obtained to date with this procedure.

Subcommittee IX on Chemical Resistance (R. H. Steiner, chairman) reports that the formulation of the test method for chemical resistance has been completed and will be submitted to the committee for balloting during the ensuing year. This method augments the Tentative Method of Test for Chemical Resistance of Hydraulic Cement Mortars (C 267 – 51 T) accepted at the 1951 Annual Meeting.

This report has been submitted to letter ballot of the committee, which consists of 22 members; 22 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

F. O. ANDEREGG,
Chairman.

BEAUMONT THOMAS,
Secretary.

REPORT OF COMMITTEE C-7

ON

LIME*

Committee C-7 on Lime held two meetings during the past year: at Atlantic City, N. J., on June 22, 1951, and at Cleveland, Ohio, on March 7, 1952.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, James A. Murray.
Vice-Chairman, Walter C. Voss.
Vice-Chairman, E. E. Eakins.
Secretary, Robert S. Boynton.

ADOPTION OF TENTATIVE AS STANDARD

Committee C-7 recommends that the following tentative specifications be approved without change for reference to letter ballot of the Society for adoption as standard:

Specification for Quicklime for Calcium Carbide Manufacture (**C 258 – 50 T**), and

Specification for Hydrated Lime for Grease Manufacture (**C 259 – 50 T**).

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee C-7 recommends that the Standard Specifications for Quicklime and Hydrated Lime for Water Treatment (C 53 – 50) be revised as appended hereto[1] and reverted to tentative status.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following standards which have been published for six years or longer without revision, and which are considered to be in accord with present practice:

Standard Specifications for:

Quicklime for Structural Purposes (C 5 – 26),
Sand for Use in Plaster (C 35 – 39),
Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (C 45 – 25),
Quicklime for Sulfite Pulp Manufacture (C 46 – 27),
Hydrated Lime for Varnish Manufacture (C 47 – 27), and
Quicklime and Hydrated Lime for Silica Brick Manufacture (C 49 – 42).

Standard Methods of:

Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (C 50 – 27).

The recommendation appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee accomplishments include the development of a new settling test for lime, progress made on new methods of determining available CaO and iron content of lime, and development of a new slaking test for quicklime.

This report has been submitted to letter ballot vote of the committee, which consists of 47 members; 38 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

WALTER C. VOSS,
Chairman.

ROBERT S. BOYNTON,
Secretary.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The revised specifications were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting there was presented to the Society through the Administrative Committtee on Standards the recommendation of Committee C-7, jointly with Committee C-11 on Gypsum, that Specifications for Inorganic Aggregates for Use in Interior Plaster be published as tentative to replace Standard Specifications for Sand for Use in Plaster (C 35 – 39). This recommendation was accepted by the Standards Committee on September 5, 1952, and the new tentative specifications appear in the 1952 Book of ASTM Standards, Part 3, bearing the designation C 35 – 52 T.

On December 12, 1952, the Administrative Committee on Standards accepted the recommendation of Committtee C-7 that the Standard Specification for Quicklime and Hydrated Lime for Water Treatment (C 53 – 39) be revised and reverted to tentative. The revised specification appears in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-8

ON

REFRACTORIES*

Committee C-8 on Refractories has held two meetings during the past year: the eightieth in Bedford Springs, Pa., on September 13, 1951, and the eighty-first in Cleveland, Ohio, on March 4, 1952.

The committee has lost by death Clarence E. Fulton of the Pittsburgh Plate Glass Co. The present membership is 39, of whom 20 are classified as producers, 12 as consumers, and 7 as general interest members. There are 18 consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. B. Sosman.
Vice-Chairman, J. J. Hazel.
Secretary, W. R. Kerr.

NEW TENTATIVE

Committee C-8 recommends for publication as tentative the following method of test, as appended hereto:[1]

Tentative Method of Test for Disintegration of Fireclay Refractories in an Atmosphere of Carbon Monoxide.

This method has been published as information in the 1950 *Proceedings* and also in the 1948 and 1952 editions of the committee's manual.[2] Minor changes were accepted by the committee at its recent meeting.

TENTATIVE REVISION OF STANDARDS

Standard Definitions of Terms Relating to Refractories (**C 71 – 51**).[3]—The committee recommends for publication the following tentative revision of this standard:

Add the following two definitions to the existing list:

Refractories (*noun*).—Nonmetallic materials of construction capable of withstanding high temperature and other conditions encountered in the operation of industrial furnaces.

Refractory (*adjective*).—As applied to nonmetallic materials, resistant to the high temperature and other conditions encountered in the operation of industrial furnaces.

Standard Methods of Test for Crushing Strength and Modulus of Rupture of Insulating Fire Brick at Room Temperature (**C 93 – 46**).[4]—The committee recommends for publication the following tentative revision:

Section 4(c).—Change the rate of application of load, when using the hydraulic machine, from "750 lb. per min. ± 10 per cent" to "7000 lb. per min. ± 10 per cent."

Section 8(b).—Change the rate of application of load, when using the hydraulic machine, from "200 lb. per min. ± 10 per cent" to "1000 lb. per min. ± 10 per cent."

The purpose of these two revisions is to save time and expense by speeding up the tests. Experimental comparisons have shown conclusively that these radical increases in rate have no perceptible effect on the numerical result. The changes apply only to the hydraulic machine, not to the mechanical machine.

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* Presented at the Fifty-fifth annual meeting of the Society, June 23–27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

[2] Manual of ASTM Standards on Refractory Materials.

[3] **1951 Supplement to Book of ASTM Standards, Part 3.**

[4] **1949 Book of ASTM Standards, Part 3.**

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Methods of Chemical Analysis of Refractory Materials (C 18 – 51).[3]—The committee recommends for adoption as standard the following tentative revisions:

Sections 16(a) and 31(a).—Tentative revisions issued June, 1949.[5]

Sections 12, 23, 33, 34, 57(b), and 58.—Tentative revisions issued June, 1950.[2]

The first two items deal with minor changes in the method for alkalies and silica; these have already been inadvertently introduced by the chairman into the 1952 Manual in advance of their formal adoption. The last six items deal with the colorimetric determination of titania, and have received no correction or adverse criticism since publication.

Standard Method for Basic Procedure in Panel Spalling Test for Refractory Brick (C 38 – 49).[4]—The committee recommends for adoption as standard the tentative revisions to Sections 6 and 7, issued January, 1951.[5]

Standard Method of Panel Spalling Test for High Duty Fireclay Brick (C 107 – 47).[4]—The committee recommends for adoption as standard the tentative revisions to Sections 5(*e*) and 5(*f*), issued January, 1951.[5]

Standard Method of Panel Spalling Test for Super Duty Fireclay Brick (C 122 – 47).[4]—The committee recommends for adoption as standard the tentative revisions to Sections 5(*e*) and 5(*f*), issued January, 1951.[5]

Standard Method of Panel Spalling Test for Fireclay Plastic Refractories (C 180 – 49).[4]—The committee recommends for adoption as standard the tentative revisions to Sections 6(*e*) and 6(*f*), issued January, 1951.[5]

These revisions of the four standards named above provide for more careful and reproducible cooling of the panels in the panel spalling test.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following ten standards which have been published for six years or more without revision and which are to be continued as standards, since no revisions are being recommended at the present time:

Standard Method of:

Testing Refractory Brick under Load at High Temperatures (C 16 – 49),
Test for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick (C 20 – 46),
Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 46),
Test for Sieve Analysis and Water Content of Refractory Materials (C 92 – 46),
Test for Reheat Change of Refractory Brick (C 113 – 46),
Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 49),
Test for Size and Bulk Density of Refractory Brick (C 134 – 41),
Test for Combined Drying and Firing Shrinkage of Fireclay Plastic Refractories (C 179 – 46),
Test for Reheat Change of Insulating Fire Brick (C 210 – 46), and
Standard Symbols for Heat Transmission (C 108 – 46).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

MANUAL

The principal accomplishment of the committee during the year is the publication in April, 1952, of the seventh edition of the Manual of ASTM Standards on Refractory Materials. It is 17 per cent larger (294 pages) than the sixth edition, containing as the principal new items a survey of service conditions in incinerators, and a glossary of terms prepared by the American Refractories Institute.

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[5] 1950 Supplement to Book of ASTM Standards, Part 3.

[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (R. P. Stevens, chairman) has ten surveys on its agenda for revision or for preparation as new items for the next edition of the Manual.

Subcommittee III on Tests (S. M. Phelps, chairman) has approved the recommendations on methods of test given elsewhere in this report.

Section (A) on Load (L. J. Trostel, chairman) has continued its study of third-point loading but is not recommending any change in the present methods of test.

Section (B) on Spalling (R. S. Bradley, chairman) is conducting tests on kaolin and alumina mixtures as a mortar in the panel spalling test. Changes in various requirements, such as those regarding constancy of temperature, are under consideration. In response to an inquiry from the committee, the section concludes that "ninety-degree cracks which cause the test brick to break during the cleaning operation should constitute a form of penalty for the samples and be reported as information," but such breakage should not be counted as "spalling loss."

Section (C) on Temperature (J. L. Carruthers, chairman) is studying the effects of variation in the length and thickness of test cones.

Section (F) on Refractory Insulation (W. L. Stafford, chairman) has conducted extensive comparative tests which show that the proposed increase in rate of loading by the hydraulic machine is without effect on the strength as read.

Section (G) on Porosity and Permanent Volume Change (S. M. Swain, chairman) is comparing five methods for the bulk density of granular refractories.

Section (H) on Mortars and Plastic and Castable Refractories (F. A. Lobaugh, chairman) is looking into current practice in the designation of "coarse" and "fine" particles in castable refractories. It is examining also the amount of tamping that is best for the preparation of test specimens.

Section (I) on Carbon Monoxide Disintegration (H. M. Kraner, chairman) has been redesignated Section (J), to avoid confusion.

Subcommittee VII on Specifications (J. D. Sullivan, chairman) is working on the methods of specifying particle size and has contributed comments on several Canadian and U. S. Federal specifications on refractories.

Subcommittee IX on Classifications (J. J. Hazel, chairman) is looking into current commercial usage with respect to the terms "mullite" and "sillimanite," and is considering reclassification of high-duty brick and super-duty brick with respect to their spalling characteristics.

Subcommittee X on Petrography (A. W. Allen, chairman) has been reactivated and renamed "Subcommittee X on Microscope Methods."

Subcommittee XI on Special Refractories (H. Wilson, chairman) has postponed the project of raising a special fund for research on special refractories until arrangements shall have been completed for cooperation with the Special Refractories Association. Materials to be studied include silicon carbide, fused alumina, fused magnesia, and fused alumina-silica refractories.

A new Subcommittee XV has been formed with the duty of defining (with the aid of VI), classifying (with the aid of IX), and considering tests for basic granular refractories.

The committee has voted to increase its working membership, but not its voting membership, by electing an associate member from each of the organizational members that desires to be thus represented. A special subcommittee will be appointed to recommend to the Advisory Committee the best means for putting this change into effect.

This report has been submitted to Letter ballot of the committee, which consists of 39 members; 38 members returned their ballot, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

ROBERT B. SOSMAN,
Chairman.

W. R. Kerr,
Secretary.

REPORT OF COMMITTEE C-9

ON

CONCRETE AND CONCRETE AGGREGATES*

Committee C-9 on Concrete and Concrete Aggregates, held three meetings last year: on June 20, 1951, during the Annual Meeting of the Society in Atlantic City, N. J.; on October 26, 1951, at Purdue University, West Lafayette, Ind.; and on March 5, 1952, in Cleveland, Ohio, during the Spring Committee Week of the Society.

During 1951 the committee suffered the loss through death of two longtime members: Frank E. Richart and Meyer Hirschthal. With the death of Frank Richart on July 16, 1951, Committee C-9 lost a much-respected member who joined the committee in 1922, served as its chairman from 1944 to 1946, and was elected an Honorary Member in 1950. With the death of Meyer Hirschthal on October 15, 1951, Committee C-9 lost a faithful member who joined the committee in 1935 as a representative of the American Railway Engineering Assn.

The committee takes great pleasure in announcing the election of F. H. Jackson to honorary membership. Mr. Jackson has been a member since 1926 and served as chairman from 1938 to 1944.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. W. Teller.
Vice-Chairman, Fred Hubbard.
Secretary, Bryant Mather.

The Sanford E. Thompson Award, established by the committee in 1938, in honor of its first chairman, is made for a paper of outstanding merit on concrete and concrete aggregates presented before the Society. The award this year will be made to H. F. Gonnerman and William Lerch, Portland Cement Assn., whose paper entitled "Changes in Characteristics of Portland Cement as Exhibited by Laboratory Tests over the Period 1904 to 1950" was presented at the 1951 Annual Meeting.[1]

NEW TENTATIVES

The committee recommends that the following methods be accepted for publication as tentative, as appended hereto:[2]

Tentative Methods of Test for:

Potential Reactivity of Aggregates, Chemical Test,
Resistance of Concrete Specimens to Freezing and Thawing, and
Flexural Strength of Concrete Using a Simple Beam with Center-Point Loading.

Tentative Recommended Practice for:

Petrographic Examination of Aggregates for Concrete.

Tentative Descriptions of:

Constituents of Natural Mineral Aggregates.

REVISION OF TENTATIVES

The committee recommends for revision and continuation as tentative the following:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Issued as separate ASTM publication, STP No. 127.

[2] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

Tentative Method of Testing Air-Entraining Admixtures for Concrete (C 233 – 50 T):[3]

Section 2(b).—Delete the tabulation headed "Coarse Aggregate" and the heading of the tabulation "Fine Aggregate" and insert, to replace the words "Fine Aggregate," the line: "(*1*) Fine Aggregate Grading:" Add a new paragraph to replace the tabulation headed Coarse Aggregate, to read as follows: "(*2*) Coarse Aggregate Grading: The coarse aggregate shall be separated on the 1-in., $\frac{3}{4}$-in., $\frac{1}{2}$ in., $\frac{3}{8}$ in., and No. 4 sieves and shall be recombined for use by taking equal portions of the four sizes of material produced by the separation."

Section 3 (a).—In line 3 change "5.0" to "5.5" and change the values in the tabulation at the end of this section from:

46	42
41	37

to:

45	41
40	36

Table I.—In column 1, line 2, change "Unit weight and air content" to "Air Content."

Section 5 (b).—Delete the words "Unit weight and" from the title and add the following to the paragraph, "or Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method (ASTM Designation: C 231)."

Section 7 (a).—Change "2, 7, 28, 180, and 365 days" to "3, 7, 28 days, 6 mo., and 1 yr."

Section 7 (b).—Change "2, 7, 28, 180, and 365 days" to "3, 7, 28 days, 6 mo., and 1 yr."

Section 7 (e).—Change "2, 7, 28, 180, and 365 days" to "3, 7, 28 days, 6 mo., and 1 yr."

Note 1 to Section 7.—In line 6 change "180 and 365 days" to "6 mo. and 1 yr."

Section 8 (2).—Insert after "lot number," the words "character of the material,".

Tentative Specifications for Air Entraining Admixtures for Concrete (C 260 – 50 T):[3] *Section 3 (f)*.—Change "180, and 365 days" to "6 mo, and 1 yr."

Tentative Method of Test for Fundamental Transverse Frequency of Concrete Specimens for Calculating Young's Modulus of Elasticity (Sonic Method), (C 215 – 51 T):[4] Replace this method with Tentative Method of Test for Fundamental Transverse and Torsional Frequencies of Concrete Specimens (C 215 – 52 T).[5]

Tentative Method of Test for Water Retention Efficiency of Methods for Curing Concrete (C 156 – 44 T):[6] Replace this method with the Tentative Method of Test for Water Retention Efficiency of Liquid Membrane-Forming Compounds and Impermeable Sheet Materials for Curing Concrete (C 156 – 52 T).[5]

Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method (C 231 – 49 T):[6]

Section 1.—Revise to read as follows:

> This method of test covers the procedure for determining the air content of freshly mixed concrete by one form of pressure method. Apparatus not conforming in every detail to that described may likewise be used, provided that the apparatus is designed to conform in its essential details as to capacity, general proportions, and accuracy with that herein described.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption, revisions of its standards, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

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[3] 1950 Supplement to Book of ASTM Standards, Part 3.

[4] 1951 Supplement to Book of ASTM Standards, Part 3.

[5] The revised tentative method was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

[6] 1949 Book of ASTM Standards, Part 3.

Standard Method of Test for Measuring Mortar-Making Properties of Fine Aggregate (C 87 – 47):[6]

Section 4 (*a*).—Change entire paragraph to read as follows:

> *Apparatus.*—The flow table, flow mold, and caliper used in this test shall conform to the requirements of Tentative Specifications for Flow Table for Use in Tests of Hydraulic Cement (ASTM Designation C 230). The tamper and trowel shall conform to the requirements of Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (ASTM Designation C 109).

4 (*b*).—Change first three sentences to read as follows:

> (*b*) *Procedure.*—The flow-table top shall be carefully wiped clean and dry and the flow mold placed at the center. Immediately after completing the mixing operation, a layer of mortar about 1 in. in thickness shall be placed in the mold and tamped 20 times with the tamper. The tamping pressure shall be just sufficient to insure uniform filling of the mold. The mold shall then be filled with mortar and tamped as specified for the first layer. The mortar shall then be cut off to a plane surface, flush with the top of the mold, by drawing the straight edge of a trowel (held nearly perpendicular to the mold) with a saw motion across the top of the mold. The table top shall be wiped clean and dry, being especially careful to remove any water from around the edge of the flow mold. The mold shall be lifted away from the mortar 1 min after completing the mixing operation. Immediately the table shall be dropped through a height of $\frac{1}{2}$ in. 10 times in 6 sec. The flow is the resulting increase in average diameter of the mortar mass, measured on at least four diameters at approximately equi-spaced intervals, expressed as a percentage of the original diameter.

Standard Method of Slump Test for Consistency of Portland-Cement Concrete (C 143 – 39).[6]

Revise the title to read: "Standard Method of Test for Slump of Portland-Cement Concrete."

Section 1.—Change "consistency" to "slump."

Section 5.—Change "consistency" to "slump" and delete the words "which shall be known as the slump."

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the following standards be revised as appended hereto[5] and reverted to tentative status:

Standard Method of Test for Volume Change of Cement Mortar and Concrete (C 157 – 43),

Standard Specifications for Concrete Aggregates (C 33 – 49),

Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 – 49), and

Standard Method of Sampling Fresh Concrete (C 172 – 44).

TENTATIVE REVISION OF STANDARD

The committee recommends tentative revisions of the Standard Method of Test for Cement Content of Hardened Portland-Cement Concrete (C 85 – 42)[6] as follows: *Section 4.*—In paragraph (*a*), change the sentence reading "Decant through an ignited and weighed Gooch crucible which contains a mat of short asbestos shreds, practically insoluble in HCl, thick enough to be opaque to light" to read as follows: "Decant through a Gooch crucible fitted snugly with a disk of No. OK Munktell's filter paper."

Add the following new Paragraph (*c*):

> (*c*) The filtrate from the silica determination contains the soluble constituents from the aggregates and the cement. Determine the soluble calcium oxide in the filtrate (after removal of the iron and aluminum hydroxides) in accordance with either Section 13 of the Stand-

ard Methods of Chemical Analysis of Portland Cement (ASTM Designation: C 114), or Section 12 of the Standard Methods of Chemical Analysis of Limestones, Quicklime, and Hydrated Lime (ASTM Designation: C 25). If the tests thus far have indicated that the aggregates are largely siliceous, use the entire filtrate for the calcium oxide determination; otherwise use an aliquot thereof.

Section 5.—To include the determination of the soluble calcium oxide as well as the soluble silica, change to read as follows by the addition of the italized words:

5. *Correction Factors.* Whenever the aggregates are available that were used in the concrete being analyzed, blank tests shall be run on these aggregates to determine their content of silica *and of calcium oxide,* soluble under the conditions of the test (Section 4). These contents of soluble silica *and calcium oxide* shall then be used as correction factors and be subtracted from the total soluble silica *and calcium oxide* found in the concrete, the difference being due to the cement contained in the specimen.

Section 6.—To include the calcium oxide determination change to read as follows by the addition of the italicized words:

The percentage of cement in the sample shall be calculated by dividing the corrected percentage of soluble silica found by the factor 0.2175[4], and *the corrected percentage of soluble calcium oxide found by the factor 0.630,* provided it is not known that the silica and calcium oxide contents of the cement differ from these values. Whenever possible, the *known values* shall be taken as the factors.

Add a new section as follows:

7. *Acceptance of Results.* When the cement content determinations by the soluble silica and the soluble calcium oxide procedures differ from each other, the analyst is directed to accept the *lower* value.

These tentative revisions are based on the results of a cooperative investigation sponsored by Subcommittee III-1 on Miscellaneous Tests of Hardened Concrete. The investigation involved tests on six concrete specimens performed at seven laboratories. The results are appended hereto.[6]

REAFFIRMATION OF STANDARDS

The committee recommends that the following standards which have stood without revision for six or more years be reaffirmed as standard:

Standard Methods of Test for:

Unit Weight of Aggregate (C 29 – 42),
Voids for Aggregate in Concrete (C 30 – 37),
Coal and Lignite in Sand (C 123 – 44),
Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 – 39),
Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42),
Specific Gravity and Absorption of Fine Aggregate (C 128 – 42),
Sieve Analysis of Fine and Coarse Aggregates (C 136 – 46),
Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (C 138 – 44),
Clay Lumps in Aggregates (C 142 – 39), and
Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 – 46).

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that the following tentatives, which have stood without revision for two or more years be retained as tentative:

Tentative Specifications for:

Waterproof Paper for Curing Concrete (C 171 – 49 T),

Tentative Methods of Test for:

Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 – 46 T),
Air Content (Volumetric) of Freshly Mixed Concrete (C 173 – 42 T),
Bleeding of Concrete (C 232 – 49 T),
Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel (C 234 – 49 T), and
Soft Particles in Coarse Aggregates (C 235 – 49 T).

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[6] See p. 282.

OTHER RECOMMENDATIONS

The committee has approved a revision of the Standard Definition of the Term Sand (C 58 – 28) which has been referred to Committee E-8 on Nomenclature and Definitions for review. The revision involves the replacement of the present "Note" by the following:

> NOTE.—When used without a qualifying adjective, the term is generally understood to mean the product of the natural disintegration of siliceous or calcareous rock. The fine material resulting from the crushing of rock, gravel, or blast-furnace slag[7] is known as manufactured sand. The gradation and other physical characteristics should be taken care of in specifications.

The committee has approved the Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 – 50 T), a method under the jurisdiction of Committee C-1 on Cement, as a method of test for concrete aggregates.

The committee recommends the continuance, without change, of the Standard Specifications for Lightweight Aggregates for Concrete (C 130 – 42), pending revision.

SUBCOMMITTEE ACTIVITIES

The work of Committee C-9 is carried out by three groups of subcommittees: Group I, Administration, Fred Hubbard, Chairman; Group II, Research, A. T. Goldbeck, Chairman; and Group III, Specifications and Test Methods, Stanton Walker, Chairman. A new Subcommittee, III-p, on Manual of Concrete Testing, was appointed during the year. All the subcommittees have been active during the year, and many of those that have not been responsible for recommendations included in this report may be expected to have such recommendations in the near future.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[8]

This report has been submitted to letter ballot of the committee, which consists of 117 members commanding 93 votes, plus 7 honorary members having voting privileges; 90 members returned their ballots, of whom 85 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

K. B. WOODS,
Chairman.

BRYANT MATHER,
Secretary.

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[7] See Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 – 48), 1949 Book of ASTM Standards, Part 3.

[8] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

APPENDIX

CEMENT CONTENT DETERMINATION AND REACTIVE AGGREGATE COOPERATIVE LABORATORY TESTS*

During the past year Subcommittee III-1 undertook a cooperative laboratory investigation to determine the extent, if any, to which the inclusion of an aggregate of known chemical reactivity might affect the cement content determinations in the ASTM method of test C 85 - 42.

The subcommittee members were further requested to determine the calcium oxide content in the solutions obtained in the above procedure with a view to determining whether this constituent would add to the value of the present method, which is based on the silica content for the determination of the cement content of the concrete. For this purpose the following materials were selected:

(*a*) A dolomite from the Niagaran formation found in northern Ohio typical of the aggregate production in the Woodville-Gibsonburg region and of very pure composition, having over 99 per cent calcium and magnesium carbonate in the dolomitic ratio. Both coarse and fine aggregates were prepared from this material.

(*b*) A diabase trap rock from the Kingston Trap Rock Co., Kingston, N. J., which is typical of the aggregate available in the northeastern part of the United States. Chemically this contains approximately 50 per cent silica, and mineralogically is composed essentially of augite, feldspars, and magnetite. Both coarse and fine aggregates were prepared from this material.

(*c*) An opaline rock containing over 80 per cent opal from Monticello, Calif., obtained by the courtesy of William Lerch of the Portland Cement Assn. This material was known to be reactive in concrete. For this investigation the opaline rock was crushed to obtain the fraction between the No. 8 and No. 100 sieves, so as to accentuate the surfaces exposed to the solvent action of the reagents used in the Method C 85 - 42.

(*d*) Normal portland cement, Type I, secured from the Medusa Portland Cement Co., Silica, Ohio plant with an alkali content of 0.67 per cent calculated as sodium oxide. Additions of flue dust from this cement plant were used to bring the alkali content to 1.0 per cent when needed in this investigation.

Six concrete mixes were carefully made up to include the following variables of materials in known amounts by weight:

No. 22111—Dolomite (coarse and fine aggregates) and cement (normal alkali content).

No. 22113—Dolomite (coarse and fine aggregates), cement (normal alkali content), and 5 per cent of reactive opaline rock (No. 8–No. 100 sieve fraction).

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* Submitted by Subcommittee III-1 on Miscellaneous Tests on Hardened Concrete, as information only.

No. 22115—Dolomite (coarse and fine aggregates), cement (high alkali content), and 5 per cent of reactive opaline rock (No. 8–No. 100 sieve fraction).

No. 22112—Trap rock (coarse and fine aggregates) and ce-

TABLE I.—SOLUBLE SILICA—AVERAGE VALUES REPORTED BY INDIVIDUAL LABORATORIES.

LABORATORY	SAMPLE NUMBER					
	22111	22112	22113	22114	22115	22116
	Average Soluble Silica, per cent					
A	2.67	5.35	3.11	5.57	3.02	5.99
B	3.10	5.39	3.52	5.69	3.29	5.83
C	2.88	5.40	3.61	6.19	3.80	6.72
D	2.81	5.25	3.04	5.18	2.97	5.27
E	2.91	5.66	3.57	6.24	3.31	6.05
F	2.98	6.14	3.40	6.13	3.40	5.99
G	2.93	6.24	3.43	6.95	3.34	6.80
General Average	2.90	5.63	3.38	5.99	3.30	6.09
Calculated to be present from known constituents	3.03	5.29	3.28	5.41	3.33	5.44

TABLE II.—SOLUBLE CALCIUM OXIDE—AVERAGE VALUES REPORTED BY INDIVIDUAL LABORATORIES.

LABORATORY	AVERAGE SOLUBLE CALCIUM OXIDE, PER CENT					
	Sample 22111	Sample 22112	Sample 22113	Sample 22114	Sample 22115	Sample 22116
A	34.12	9.77	33.08	9.53	32.62	9.09
B	34.68	9.69	33.17	9.52	33.21	9.22
C	34.75	9.68	33.24	9.47	33.05	9.41
D	35.43	9.32	34.22	9.40	33.68	8.80
E	34.21	9.66	33.08	9.41	32.88	9.12
F	34.79	10.01	33.54	9.27	33.36	9.30
G	34.39	10.39	33.66	10.06	33.37	9.69
General Average	34.62	9.79	33.43	9.52	33.17	9.23
Calculated to be present from known constituents	34.11	9.37	32.80	9.34	32.50	8.86

TABLE III.—SOLUBILITY DATA OF SEPARATE CONSTITUENTS USED IN CONCRETE SPECIMENS.

(Rendered soluble under condition of C 85 – 42)

	SOLUBLE SILICA AND CALCIUM OXIDE, PER CENT				
	Dolomite	Traprock	Opaline Rock Reactive Aggregate	Normal Portland Cement	Cement Flue Dust
Soluble Silica	0.05	2.75	5.85	21.70	24.01
Soluble Calcium Oxide	30.75	0.80	0.28	63.00	37.01

TABLE IV.—CALCULATED CONCRETE COMPOSITIONS FROM KNOWN ADDED CONSTITUENTS COMPARED WITH COMMITTEE AVERAGE VALUES OF SOLUBLE SILICA AND SOLUBLE CALCIUM OXIDE.

(Based on hardened concrete containing some H_2O and CO_2 when analyzed)

	Known Concrete Composition, per cent by weight	Calculated Soluble SiO_2 Present, per cent	SiO_2 Found (Committee Average), per cent	Calculated Soluble CaO Present, per cent	CaO Found (Committee Average), per cent
SAMPLE No. 22111					
Cement	13.77	2.99		8.68	
Dolomite (coarse and fine aggs.)	82.61	0.04		25.43	
H_2O retained	2.78				
CO_2 gained	0.84				
	100.00	3.03	2.90	34.11	34.62
SAMPLE No. 22112					
Cement	13.82	3.01		8.71	
Traprock (coarse and fine aggs.)	82.93	2.28		0.66	
H_2O retained	2.01				
CO_2 gained	1.24				
	100.00	5.29	5.69	9.37	9.79
SAMPLE No. 22113					
Cement	13.75	2.98		8.67	
Dolomite (coarse and fine aggs.)	78.36	0.04		24.12	
Opaline rock	4.12	0.24		0.01	
H_2O retained	2.39				
CO_2 gained	1.38				
	100.00	3.26	3.38	32.80	33.43
SAMPLE No. 22114					
Cement	13.80	3.01		8.70	
Traprock (coarse and fine aggs.)	78.68	2.16		0.63	
Opaline rock	4.14	0.24		0.01	
H_2O retained	2.26				
CO_2 gained	1.12				
	100.00	5.41	5.99	9.34	9.52
SAMPLE No. 22115					
Cement	12.08	2.63		7.62	
Flue dust	1.73	0.42		0.64	
Dolomite (coarse and fine aggs.)	78.73	0.04		24.23	
Opaline rock	4.14	0.24		0.01	
H_2O retained	1.95				
CO_2 gained	1.37				
	100.00	3.33	3.30	32.50	33.17
SAMPLE No. 22116					
Cement	12.03	2.62		7.58	
Flue dust	1.73	0.42		0.64	
Traprock (coarse and fine aggs.)	78.38	2.16		0.63	
Opaline rock	4.12	0.24		0.01	
H_2O retained	2.37				
CO_2 gained	1.37				
	100.00	5.44	6.09	8.86	9.23

ment (normal alkali content).

No. 22114—Trap rock (coarse and fine aggregates), cement (normal alkali content), and 5 per cent of reactive opaline rock (No. 8–No. 100 sieve fraction).

No. 22116—Trap rock (coarse and fine aggregates), cement (high alkali content), and 5 per cent of reactive opaline rock (No. 8–No. 100 sieve fraction).

After moist curing for 28 days, the cylinders from the above concrete mixes were air dried for a week, oven dried at 105 C for two days, and were then crushed in a compression machine, reduced further by hand with a hammer, then a jaw crusher, and finally by a disk pulverizer to obtain the fineness required for the test samples. In each stage of reduction, care was taken to avoid any loss of material, particularly of the finer fractions, since these normally contain higher percentages of the cement. In all cases the amount of concrete taken for the samples was approximately 15 lb. Representative portions were then secured by quartering and subdividing until approximately 1-lb samples were obtained, which were then sent to each of the seven cooperating laboratories for analysis by the C 85 – 42 method of test for the content of soluble silica.

The results obtained by the seven cooperating laboratories are given in Tables I, II, III and IV.

Three additional steps are shown in Table V:

1. The correction of the total soluble silica and calcium oxide values to the respective values due to the cement only.

2. The conversion of these corrected values to cement content of the concrete by use of the factors of 0.2170 for the silica and 0.630 for the calcium oxide in the cement used.

TABLE V.—SOLUBLE SILICA AND CALCIUM OXIDE VALUES.

	Sample 22111	Sample 22112	Sample 22113	Sample 22114	Sample 22115	Sample 22116
Average value of total soluble silica found, per cent	2.90	5.69	3.38	5.99	3.30	6.09
Correction for soluble silica in constituents other than cement, per cent	0.04	2.28	0.28	2.40	0.28	2.40
Soluble silica due to cement only, per cent	2.86	3.41	3.10	3.59	3.02	3.69
Equivalent cement content, using factor 0.2170 (soluble silica in this cement), per cent	13.18	15.71	14.29	16.54	13.92	17.00
Known cement content, per cent	13.77	13.82	13.75	13.80	13.81	13.76
Average value of total soluble calcium oxide found, per cent	34.62	9.79	33.43	9.52	33.17	9.23
Correction for soluble calcium oxide in constituents other than cement, per cent	25.43	0.66	24.13	0.64	24.24	0.64
Soluble calcium oxide due to cement only, per cent	9.19	9.13	9.30	8.88	8.93	8.59
Equivalent cement content, using factor 0.630 (soluble calcium oxide in this cement), per cent	14.59	14.49	14.76	14.10	14.17	13.63
Known cement content, per cent	13.77	13.82	13.75	13.80	13.81	13.76

3. The comparison of these results obtained by the analytical procedure with the known values.

SUMMARY AND CONCLUSIONS

1. The results obtained by seven cooperating laboratories with the present ASTM Method of Test C 85 – 42 for soluble silica in concrete and its extension to include soluble calcium oxide determination were generally in good agreement with each other (Table I).

2. The agreement is also generally good between the average values found and the known amounts of soluble silica and soluble calcium oxide in the components of the concrete specimens.

3. When the total amounts of soluble silica and soluble calcium oxide found have been reduced by the amount of these oxides dissolved from the aggregates and additives, the determined cement content is generally slightly higher than but reasonably close to the true cement contents, except with the samples containing trap rock (Nos. 22112, 22114, 22116) in the soluble silica procedure.

4. These exceptions deviated more from the true values when the samples contained opaline aggregate and higher alkali cement, indicating further release of soluble silica has occurred from this reactive aggregate under the conditions of concrete curing and analysis.

5. ASTM method of test C 85 – 42 detected the presence of an aggregate known to be reactive in concrete, but did not differentiate it from another aggregate of good service record but which also yielded soluble silica and calcium oxide in this investigation.

6. The soluble silica basis of concrete analysis for cement content was more accurate with concretes containing the calcareous aggregates, while the soluble calcium oxide method gave better results with the siliceous aggregates used in this investigation.

7. When the cement contents of the concrete specimens were determined by both the soluble silica and the soluble calcium oxide methods and these respective values differed from each other, the *lower* value (sub-committee corrected average) was in all cases nearer the actual value and in all cases within 0.7 per cent of the actual value (see Table V).

REPORT OF COMMITTEE C-11

ON

GYPSUM*

Committee C-11 on Gypsum met on December 6, 1951, at the National Bureau of Standards, Washington, D. C., and on March 5, 1952, in Cleveland, Ohio.

The committee now consists of 21 members of whom 8 are classified as producers, 4 as consumers, and 9 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. S. Wells.
Vice-Chairman, H. F. Gardner.
Secretary, L. H. Yeager.

Revision of Standards, Immediate Adoption

The committee recommends for immediate adoption revisions in the following four standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Methods of Testing Gypsum and Gypsum Products (C 26 – 50):[1]

Section 21 (*b*).—Delete the present paragraph in its entirety and substitute the following:

All gypsum mixtures containing aggregates shall be considered of normal testing consistency when a penetration of 20 ± 3 mm is obtained when tested in accordance with Section 20, weight of rod and plunger for these determinations to be 150 g. Normal consistency shall be expressed as the number of milliliters of water required to be added to 100 g of the mixture.

Section 25.—Delete the existing section in its entirety and substitute the following:

25 Test Specimens.—Molds for making test specimens shall be 2-in. split cube molds made of noncorrodible material and sufficiently rigid to prevent spreading during molding. The molds shall have not more than three cube compartments and be separable into not more than two parts. When assembled, the parts of the molds shall be firmly held together, and dimensions shall conform to the following requirements.

Interior faces shall be plane surfaces with a maximum variation 0.001 in. for new molds and 0.002 in. for old molds; distance between opposite faces, and height of the molds, measured separately for each cube compartment, shall be 2 ± 0.005 in. for new molds, or 2 ± 0.020 in. for old molds; angle between adjacent interior faces and between interior faces and top and bottom planes of the mold shall be 90 ± 0.05 deg measured at points slightly removed from the intersection of the faces.

Sufficient sample shall be mixed at normal consistency as determined in Sections 19 to 21 to produce not less than 1000 ml of mixed mortar. Neat gypsum plaster shall be premixed dry with 2 parts by wt. of standard Ottawa testing sand. Add required amount of water to a clean 2-qt mixing bowl. Add required amount of dry plaster. Allow to soak 2 min. Mix vigorously for 1 min. with a metal spoon or stiff-bladed spatula to produce a mortar of uniform consistency.

A layer of mortar about 1 in. in depth shall be placed in each mold and puddled 10 times across the mold between each pair of opposite faces with a 1-in. wide metal spatula, to remove air bubbles. The molds shall then be filled to a point slightly above the tops of the molds, by the same filling and puddling procedure used for the first mold with the straight edge of the spatula. The cubes shall be retained in the molds in moist air until thoroughly hardened (90 to 100 per cent humidity), but not less than

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 3.

24 hr. The specimens shall then be removed from the molds and dried at a temperature of not less than 70 F (21.1 C) nor more than 100 F (37.8 C) in an atmosphere having a relative humidity of not more than 50 per cent. The specimens shall be weighed at 1-day intervals until the weight has become constant to within 0.1 per cent. Dry test specimens shall be placed in a desiccator over anhydrous calcium chloride for 24 hr, removed, and tested immediately.

New Section.—Add a new section to read as follows:

WATER RESISTANCE CHARACTERISTICS OF CORE-TREATED WATER-REPELLENT GYPSUM SHEATHING

38. *Procedure.*—Prepare a 12 by 12 by $\frac{1}{2}$-in. sample from the center of a 2 by 8 ft by $\frac{1}{2}$-in. gypsum sheathing board by scoring and breaking. Samples shall be cut 6 in. in from both edges and at least 6 in. from either end. The edges of the sample are not to be treated and the surface paper must not be damaged.

The samples shall be stored to constant weight within 0.1 per cent at a temperature of 60 to 85 F in an atmosphere having a relative humidity of from 25 to 60 per cent and then accurately weighed to within 0.5 g.

Immerse the sample flatwise in a body of water at a constant temperature of 70 F ± 1F with a head of 1 in. of water over the top of the sample which is so positioned in the water bath that it does not lie flat on the bottom of the container.

Upon removal from the bath, excess water shall be wiped from the surfaces and edges and the sample weighed immediately to 0.5 g.

Standard Specifications for Gypsum Wall Board (C 36 – 50):[1]

Section 3.—Make the following addition to the present tabulation:

Thickness, in.	Load, lb	
	Bearing edges across Fiber of Surfacing	Bearing edges parallel to Fiber of Surfacing
$\frac{5}{8}$	145	55

Section 5 (a).—Delete the existing paragraph and substitute the following:

5 (*a*) *Thickness.*—The nominal thickness of gypsum wallboard shall be $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, or $\frac{5}{8}$ in. with permissible variations in the nominal thickness of $\pm\frac{1}{64}$ in. and with permissible local variations of $\pm\frac{1}{32}$ in. from the nominal thickness. Edges of $\frac{3}{8}$-in., $\frac{1}{2}$-in., and $\frac{5}{8}$-in. board may be plain, either recessed or tapered to receive a joint reinforcing strip; if recessed, the depression shall not be less than 0.020 in. nor more than 0.045 in.; if tapered, the depression at $\frac{1}{4}$ in. in from the edge of wallboard shall not be less than 0.020 in. nor more than 0.045 in.

Section 5 (d).—Make the following addition to the present tabulation:

Thickness, in.	Weight per 1000 sq ft, lb	
	Min	Max
$\frac{5}{8}$	2250	3150

Other tolerances to be the same as for $\frac{1}{2}$-in. gypsum wall board.

Standard Specification for Gypsum Sheathing Board (C 79 – 50):[1]

Section 2.—Add the following at the end of the paragraph:

Core treated water-repellent gypsum sheathing shall have, in addition, incorporated in the core a water-repellent material.

New Section.—Add a new Sec. 4 to read as follows, renumbering the subsequent sections accordingly:

4. *Water Resistance of Core-Treated Water-Repellent Gypsum Sheathing.*—The average water absorption of three specimens selected at random, when tested in accordance with Methods C 26, shall be less than 10 per cent by weight after 2-hr immersion.

The recommendation in this report has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee, which consists of 21 members; 18 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. S. WELLS,
Chairman.

L. H. YEAGER,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting there was presented to the Society through the Administrative Committee on Standards the recommendation of Committee C-11, jointly with Committee C-7 on Lime, that Specifications for Inorganic Aggregates for Use in Interior Plaster be published as tentative to replace Standard Specifications for Sand for Use in Plaster (C 35 – 39). This recommendation was accepted by the Standards Committtee on September 5, 1952, and the new tentative specifications appear in the 1952 Book of ASTM Standards, Part 3, bearing the designation C 35 – 52 T.

REPORT OF COMMITTEE C-12

ON

MORTARS FOR UNIT MASONRY*

Committee C-12 on Mortars for Unit Masonry held two meetings during the past year: on June 21, 1951, in Atlantic City, N. J., and on March 6, 1952, in Cleveland, Ohio.

At the present time, the committee consists of 39 members, of whom 16 are classified as producers, 11 as consumers, and 12 as general interest members. There are 4 consulting members.

The election of officers for the ensuing two-year term resulted in the selection of the following:

Chairman, J. M. Hardesty.

First Vice-Chairman, Harry C. Plummer.

Second Vice-Chairman, P. M. Woodworth.

Secretary, J. A. Murray.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specifications for Aggregate for Masonry Mortars (C 144 - 44)[1] be reverted to tentative status and revised as appended hereto.[2]

REVISION OF TENTATIVE

The committee recommends the following revisions in Tentative Specifications for Mortar for Unit Masonry (C 270 - 51 T),[3] and that these specifications, as revised, be continued as tentative:

Section 1.—Add the following paragraph: "Unless otherwise specified, the Proportion Specifications shall govern." This is intended to take care of cases where the contract specifications refer to C 270 - 51 T but fail to stipulate whether the Property Specifications or the Proportion Specifications shall apply.

Section 2(d).—Change to read as follows: "(*d*) *Admixtures or Mortar Colors.*—If admixtures (water repellants, plasticizing agents, etc.) or mortar colors are to be added to the mortar at time of mixing, they shall be provided for in the contract specifications."

Section 6.—After "construction" insert the words, "mixed to an initial flow of 100 to 115." This clarification is intended to remove the present ambiguity concerning the initial flow of the water-retention test sample.

Section 8(a).—Add the following words "except as noted in Section 6 above." It was considered advisable to refer back to Section 6, which requires that the mortar shall be of the materials, and of the proportions of dry materials, that are to be used in the construction.

Section 8(b) (1).—After "construction" add the words "mixed to a flow of 100 to 115."

Table II.—Delete the footnote to this table. There has been considerable criticism of this footnote because (*a*) it tends to classify lime as strictly a plasticizing agent, whereas lime has cementitious properties, and (*b*) it would permit the use of excessive proportions of a variety of plasticizing agents, subject

only to control by the building official. Deletion of the footnote does not preclude the use of such agents (see proposed revision of Section 2(*d*)), but it does prevent their use in place of the specified proportion of lime.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 3.

[2] The revised specifications were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

[3] 1951 Supplement to Book of ASTM Standards, Part 3.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Mortar for Reinforced Brick Masonry (C 161 – 41 T), be retained as tentative without revision. When the Tentative Specifications for Mortar for Unit Masonry (C 270 – 51 T) have been adopted as standard, Specification C 161 T will either be withdrawn or revised to conform to the requirements of the general mortar specifications.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Specifications and Methods of Tests for Mortar (R. E. Copeland, chairman) held two meetings during the past year during which suggested revisions of the Tentative Specifications for Mortar for Unit Masonry (C 270 T) were considered.

Subcommittee IV, on Specifications for Aggregates for Mortar (Stanton Walker, chairman) held one meeting during the year and, as a result of this meeting and correspondence, proposed the revisions to Specifications for Aggregate for Masonry Mortar which are recommended by the committee.

Working Subcommittee on Efflorescence (P. L. Rogers, chairman) held two meetings during the past year and organized a cooperative testing program, to be conducted by laboratories represented on the subcommittee and others, to establish a satisfactory method of test of mortars for efflorescence. Proposed methods of tests, including the materials involved, were agreed upon and, to date, results of tests conducted under this program indicate substantial progress towards the development of a test method which can be recommended to the committee as tentative.

At the request of this subcommittee, F. O. Anderegg prepared a paper on the subject of efflorescence in order that the subcommittee might have a clearer picture of the problem and be better able to develop satisfactory tests for the determination of relative efflorescence of masonry mortar.[4]

This report has been submitted to letter ballot of the committee, which consists of 39 members; 28 returned their ballots, of all whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. M. HARDESTY,
Chairman

HARRY C. PLUMMER,
Secretary.

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[4] ASTM BULLETIN, No. 185, October, 1952 p. 39 (TP 155).

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-12 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Specifications for Mortar for Unit Masonry (C 270 – 51 T) be revised. This recommendation was accepted by the Standards Committee on September 5, 1952, and the revised specifications appear in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-13

ON

CONCRETE PIPE*

Committee C-13 on Concrete Pipe held one meeting during the past year in Chicago, Ill., on May 22 and 23, 1952. During the year three subcommittees met in Chicago: the Steering Subcommittee on Long Range Planning, and the Subcommittee for Correlation with the American Association of State Highway Officials on October 12 and 13, 1951, and the Subcommittee on Low-Head Pressure Pipe Specification on October 14 and 15, 1951.

The present membership of the committee consists of 34 members, of whom 17 are classified as producers, 14 as consumers, and 3 as general interests.

An election of officers was held at the May meeting with the following being elected:

Chairman, R. R. Litehiser.
Vice-Chairman, E. F. Kelley.
Secretary, H. F. Peckworth.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision in the *Standard Specifications for Reinforced Concrete Sewer Pipe* (C 75 – 41)[1] and the *Standard Specifications for Reinforced Concrete Culvert Pipe* (C 76 – 41)[1] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Section 6.—Replace the present Section 6 by the following:

> Reinforcement may consist of wire conforming to the Standard Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement (ASTM Designation: A 82), or wire fabric conforming to the Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (ASTM Designation: A 185), or of bars of structural or intermediate grade conforming to the Standard Specifications for Billet-Steel Bars for Concrete Reinforcement (ASTM Designation: A 15) of the American Society for Testing Materials.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Specifications for Concrete Sewer Pipe (C 14 – 41).[2]—Committee C-13 recommends that the tentative revisions of Sections 5 and 7 and Table I, issued in June, 1951, be approved for reference to letter ballot of the Society for adoption as standard.

Standard Specifications for Reinforced Sewer Pipe (C 75 – 41).[2]—The committee recommends that the tentative revisions of Sections 5, 7, and 8, issued in June, 1951, be approved for reference to letter ballot of the Society for adoption as standard.

As an editorial matter, the revision of Section 7 will be deleted and a new sentence added to Section 8 as a substitution which will read: "Admixtures or blends may be used with the approval of the consumer." This change of section and wording provides uniformity within all four standards on concrete pipe.

Standard Specifications for Reinforced Concrete Culvert Pipe (C 76 – 41).[2]—The committee recommends that the tentative revisions of Sections 5 and 8, issued in June, 1951, be approved for reference to letter ballot of the Society for adoption as standard.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 3.

[2] 1951 Supplement to Book of ASTM Standards, Part 3.

Standard Specifications for Concrete Irrigation Pipe (C 118 – 39).[2]—Recommendation is made that the tentative revisions of Sections 5, 6, and 7, issued in June, 1951, be approved for reference to letter ballot of the Society for adoption as standard.

The recommendations appearing in this report have been submitted to letter ballot of the Society, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee on Specifications for Low-Head Pressure Concrete Pipe (H. G. Curtis, chairman).—After a review of a proposed specification for all types of uses, the subcommittee was instructed to prepare two specifications, one for reinforced concrete low-head pressure sewer pipe and the other for reinforced concrete pressure pipe.

Subcommittee on Recommended Practice on Bedding and Backfilling (M. W. Loving, chairman).—The preparation of a recommended practice covering all types of concrete pipe has been considered to be too extensive for the committee to prepare at this time. It has been proposed that joint committees be organized with other associations for developing a recommended practice for bedding and backfilling for each specific type of usage. The American Association of State Highway Officials would be considered in connection with culvert pipe and the American Public Works Association in connection with sewer pipe. The present subcommittee was discharged.

Subcommittee on Cooperation with the AASHO (E. F. Kelley, chairman).—Action was taken by the committee at the May meeting on several recommendations from the subcommittee which will result in tentative revisions of the concrete pipe specifications, these recommendations to be submitted to the Society during the current year.

Subcommittee on Long Range Planning (W. E. Corbett, chairman).—A report of the subcommittee indicated that additional basic information is needed before the several projects which have been presented can be developed further. This subcommittee is being continued and will be charged with the consideration of interim matters which are presented between meetings of the committee.

This report has been submitted to letter ballot vote of the committee, which consists of 33 members; 24 members have returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. W. HORNER,
Chairman.

HOWARD F. PECKWORTH,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-14
ON
GLASS AND GLASS PRODUCTS*

Committee C-14 held two meetings during the past year: on October 12, 1951, at the Corning Glass Center, Corning, N. Y., and on April 30, 1952, at Pittsburgh, Pa.

The committee, as of April 30, consisted of 47 voting members, 9 nonvoting members, and 15 consulting members. The voting membership consists of 17 producers, 16 consumers, and 14 general interest members.

The present officers were reelected for another term at the Pittsburgh meeting.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Definitions of Terms Relating to Glass and Glass Products (C 162 – 49 T)[1] be approved without revision for reference to letter ballot of the Society for adoption as standard.

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following three standards, which have stood for six years or more without revision, be continued pending revisions now under consideration:

Standard Methods of Test for:

Chemical Analysis of Glass Sand (C 146 – 43),
Flexure Testing of Glass (Determination of Modulus of Rupture) (C 158 – 43), and
Chemical Analysis of Soda-Lime Glass (C 169 – 43).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following three tentatives, which have stood for two years or more without revision, be continued pending revisions now under consideration:

Tentative Methods of:

Sampling Glass Containers (C 224 – 49 T),
Test for Resistance of Glass Containers to Chemical Attack (C 225 – 49 T), and
Sampling and Testing Structural Non-Load Bearing Cellular Glass Blocks (C 240 – 50 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

SUBCOMMITTEE ACTIVITIES

Subcommittee II on Chemical Analysis (F. W. Glaze, chairman) is presently working on revisions of the Standard Method of Chemical Analysis of Glass Sand (C 146 – 43) and the Standard Method of Chemical Analysis of Soda-Lime Glass (C 169 – 43). A revision of Method C 169 for inclusion of a routine determination of boron trioxide is being reviewed in the light of comments received in the committee letter ballot.

Subcommittee IV on Physical and Mechanical Properties (J. T. Littleton, chairman).—Two task groups are active, one of which is reviewing existing methods for measuring thermal expansion, annealing and strain point, and fiber softening point. Plans for round-robin tests will await the results of this review. The second group is reviewing the Standard Method of Flexure Testing of Glass (C 158), and a revision is being developed for the purpose of clarifying the scope of this test method.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee VII on Glass Containers (K. C. Lyon, chairman).—The subcommittee has recognized a definite need for a change in the time schedule noted in Table I of the Tentative Method of Sampling Glass Containers (C 224 T) in order that the schedule may represent more truly the conditions actually in practice. Prompt consideration is planned on this proposed revision.

This report has been submitted to letter ballot of the committee, which consists of 47 members; 36 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. G. GHERING,
Chairman

F. V. TOOLEY,
Secretary.

REPORT OF COMMITTEE C-15
ON
MANUFACTURED MASONRY UNITS*

Committee C-15 and its subcommittees met on June 22, 1951, at Atlantic City, N. J., in conjunction with the Annual Meeting of the Society.

At the present time, Committee C-15 consists of 68 members, of whom 28 are classified as producers, 21 as consumers, and 19 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. W. Whittemore.

First Vice-Chairman, Theodore I. Coe.

Second Vice-Chairman, P. M. Woodworth.

Secretary, M. H. Allen.

RECOMMENDATION ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the recommendation for approval of the Tentative Specifications for Chemical-Resistant Masonry Units (C 279 – 51 T). This recommendation was accepted by the Standards Committee on September 12, 1951, and appears in the 1951 Supplement to Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions of the following nine standards[1] be approved for adoption as standard:

Standard Specifications for:

Concrete Building Brick (C 55 – 37),

Hollow Load-Bearing Concrete Masonry Units (C 90 – 44),

Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 39),

Solid Load-Bearing Concrete Masonry Units (C 145 – 40),

Structural Clay Load-Bearing Wall Tile (C 34 – 50),

Structural Clay Non-Load-Bearing Tile (C 56 – 50), and

Structural Clay Floor Tile (C 57 – 50).

Standard Methods of:

Sampling and Testing Concrete Masonry Units (C 140 – 39), and

Sampling and Testing Structural Clay Tile (C 112 – 36).[2]

REVISION OF TENTATIVE

The committee recommends that the Tentative Specifications for Structural Clay Facing Tile (**C 212 – 50 T**)[1] be revised as follows:

Section 7(a).—Revise Table III to read as follows:

TABLE III.—MAXIMUM PERMISSIBLE EXTENT OF CHIPPAGE FROM THE EDGES AND CORNERS OF FINISHED FACE OR FACES INTO THE SURFACES.

Type	Chippage in inches in from	
	Edge	Corner
FTX	⅛	¼
FTS (smooth)[a]	¼	⅜
FTS (rough)[b]	5/16	½

[a] Smooth texture is the unbroken natural die finish.

[b] Rough texture is the finish produced when the face is sanded, combed, scratched or scarified, or the die skin on the face is entirely broken by mechanical means, such as wire-cutting or wire-brushing.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 3.

[2] 1949 Book of ASTM Standards, Part 3.

Add a new Table IV to read as follows and renumber all succeeding tables:

TABLE IV.—PERCENTAGES OF SHIPMENT THAT MAY BE ALLOWED CHIPPAGE OVER MAXIMUM PERMISSIBLE IN TABLE III.

Type	Percentage Allowable	Chippage in inches in from	
		Edge	Corner
FTX	5	¼	⅜
FTS (smooth)	10	5/16	½
FTS (rough)	15	7/16	¾

STANDARDS CONTINUED WITHOUT REVISION

Committee C-15 recommends that the following two standard specifications be reaffirmed without revision:

Standard Specifications for:

Paving Brick (C 7 – 42), and
Concrete Masonry Units for Construction of Catch Basins and Manholes (C 139 – 39).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 68 members; 56 members have returned their ballots, of whom 55 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. WHITTEMORE,
Chairman.

M. H. ALLEN,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units (C 126 – 50 T),
Structural Clay Facing Tile (C 212 – 50 T), and
Chemical-Resistant Masonry Units (C 279 – 51 T).

Tentative Revision of Standard Definitions of:

Terms Relating to Structural Clay Tile (C 43 – 50).

Tentative Revision of Standard Specifications for:

Vitrified Clay Filter Block for Trickling Filters (C 159 – 51).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the revised tentatives and tentative revisions appear in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-16
ON
THERMAL INSULATING MATERIALS[*]

Committee C-16 on Thermal Insulating Materials, and its subcommittees, held two meetings during the past year: at Skytop, Pa., on October 15, 16, and 17, 1951; and at Cleveland, Ohio, on March 3, 4, and 5, 1952.

The committee, as of March 17, consisted of 67 voting members, 27 nonvoting members, and 4 consulting members. The voting membership is classified as follows: 31 producers, 19 consumers, and 17 general interest members.

The present officers were reelected for another term at the Cleveland meeting.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee C-16 presented to the Society, through the Administrative Committee on Standards, recommendations for publication of the following:

Tentative Specifications for:

Mineral Wool Blanket-Type Pipe Insulation (C 280 – 51 T), and

Mineral Wool Molded-Type Pipe Insulation (for Elevated Temperatures) (C 281 – 51 T).

These recommendations were accepted by the Standards Committee on December 13, 1951, and Specifications C 280 appear in the 1951 Supplement to Book of ASTM Standards, Part 3. Publication of Specifications C 281 was withheld pending further revisions.

NEW TENTATIVES

After the annual meeting, Committee C-16 will recommend that the following three methods and two specifications be accepted for publication as tentative:

Tentative Methods of Test for:

Density of Preformed Block Type Thermal Insulation,

Density of Preformed Pipe Covering Type Thermal Insulation,

Vibration Resistance of Preformed Thermal Insulation for Pipes,

Tentative Specifications for:

Cellular Asbestos Paper Thermal Insulation for Pipes, and Laminated Asbestos Thermal Insulation for Pipes.

REVISION OF TENTATIVE

Tentative Specifications for Mineral Wool Molded-Type Pipe Insulation (for Elevated Temperatures) **(C 281 – 51 T)**.—These specifications, revised as approved by the Administrative Committee on Standards, but with publication withheld pending further revision have now been further revised and the specifications in their revised form are appended hereto.[1]

TENTATIVE REVISION OF STANDARD

The committee recommends the following tentative revision of the Standard Method of Test for Compressive Strength of Preformed Block Type Thermal Insulation **(C 165 – 45)**.[2]

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[*] Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The revised specifications were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

[2] 1949 Book of ASTM Standards, Part 3.

Section 3 (c).—Change "225 ± 25 F" to read "a selected temperature between 215 and 250 F."

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Committee C-16 recommends for adoption as standard the tentative revisions appended[2] as editorial notes to the following two methods:

Standard Method of Test for:

Bulk Density of Thermal Insulating Cement (C 164 - 44), and
Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 - 45).

STANDARDS AND TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following two standards and two tentatives be continued in their present status without revision:

Standard Method of:

Sampling and Mixing Thermal Insulating Cement (C 163 - 44),
Test for Thermal conductivity of materials by Means of the Guarded Hot Plate (C 177 - 45),

Tentative Method of Test for:

Water Vapor Permeability of Sheet Materials Used in Connection with Thermal Insulation (C 214 - 48 T), and
Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box (C 236 - 49 T).

EDITORIAL CHANGE

Committee C-16 recommends the following editorial change in the *Standard Method of Test for Flexural Strength of Preformed Block Type Thermal Insulation* (C 203 - 51):[2]

New Section.—Add the following paragraph as "Significance" and number as Section 2, renumbering succeeding paragraphs:

> This test procedure may be used to determine the resistance of some types of preformed block insulation when transverse loads are applied normal to the surface. Values are measured at the maximum load or breaking point under specified conditions of specimen size, span between supports, and rate of load application. The formulas used are based on isotropic materials and presume that the stress-strain characteristics above and below the elastic limit are nearly alike. This method is not applicable to thermal insulations of certain types in which crushing is observable before failure is obtained in transverse bending. Numerical values should be compared only when determined on materials of similar composition and physical properties. This property is considered helpful, in combination with other appropriately selected properties, to indicate the acceptability of the product for certain uses.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee S-I on Block and Pipe Insulation (W. D. Stevens, chairman).—In addition to the several new methods and specifications mentioned earlier in this report, the subcommittee has completed a method of sampling procedure and is reviewing or balloting on proposed specifications for 85 per cent magnesia block and pipe, lime-silica block and pipe covering, mineral wool block or board for low temperatures, mineral wool block or board for elevated temperatures, mineral wool pipe insulation for low temperatures, diatomaceous earth insulation, and mineral wool board for roofs.

Subcommittee S-II on Structural Insulating Board (S. M. Van Kirk, chairman) has prepared a racking load test for structural insulation board sheathed wall panels and a method of test for determining flame resistance of interior finish materials. Considerable interest has developed among other ASTM committees relative to the flame-resistance test. Some progress has also been made on linear expansion and nail-holding test procedures.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee S-III on Thermal Insulating Cement (J. E. Gaston, chairman) has prepared proposed test methods for dried adhesion and for compressive-hardness which are now being processed through the Significance of Test and Editorial Subcommittee and will soon be circulated for full committee vote. Consideration is being given to a plasticity test method and a wet-adhesion test method.

Subcommittee T-VI on Thermal Conductivity (J. D. Babbitt, chairman) has prepared a tentative method of test for thermal conductivity of pipe insulation which will shortly be circulated for letter ballot. The method of test C 236 - 49 T for thermal conductance and transmittance of built-up sections by means of the guarded hot box has been completely revised, and the revision will shortly be circulated for letter ballot.

Subcommittee T-VII on Special Thermal Properties (G. M. Rapp, chairman) is conducting second round robin trials based on a draft of a simple inexpensive method of measuring specific heat of insulating materials. A method for determining the maximum use-temperature limit of high-temperature insulations is in an advanced formative stage. Standardization of a method for evaluating emissivity of reflective insulations is also under study.

Subcommittee S-VIII on Dimensional Standards (H. P. Hoopes, chairman) has completed its work on determination of field clearance between pipe and insulation and has agreed on a recommended clearance to be incorporated in a tentative specification. The entire committee has been asked to send suggestions to the chairman on writing specific portions of this proposed specification.

Subcommittee T-IX on Vapor Barriers for Insulation (R. H. Heilman, chairman) has approved for letter ballot a tentative method of test for water vapor permeability for thick materials. The subcommittee also approved for letter ballot definitions pertaining to water vapor transmission.

Task Group on Handleability of Thermal Insulating Blocks (W. H. Zane, chairman).—The desire to develop a method of evaluating certain characteristics of insulating blocks to obtain an index by which handleability could be gaged has so far been unsuccessful. Two impact machines which were proposed have been tested by several laboratories with favorable results. It is the opinion of the task group that it will be on the basis of data obtained from this equipment that the characteristic of handleability of an insulating block might be ascertained.

This report has been submitted to letter ballot of the committee, which consists of 67 members; 52 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. R. Queer,
Chairman.

H. G. Hill,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-16 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Laminated Asbestos Thermal Insulation for Pipes (C 299 - 52 T),
Cellular Asbestos Paper Thermal Insulation for Pipes (C 298 - 52 T), and
Mineral Wool Pipe Insulation; Molded Type (Low Temperatures) (C 300 - 52 T).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the new specifications appear in the 1952 Book of ASTM Standards, Part 3.

On December 12, 1952, the Administrative Committee on Standards accepted the following recommendations submitted by Committee C-16:

Tentative Method of:

Test for Density of Preformed Pipe Covering Type Thermal Insulation (C 302 - 52 T),
Test for Density of Preformed Block Type Thermal Insulation (C 303 - 52 T), and
Test for Vibration Resistance of Preformed Thermal Insulation for Pipes (C 304 - 52 T).

The new methods of test appear in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-17

ON

ASBESTOS-CEMENT PRODUCTS*

Meetings of Committee C-17 and its subcommittees were held at the time of the 1952 Spring Meeting of the Society on March 6, 1952, in Cleveland, Ohio.

The membership of the committee consists of 30 voting members, composed of 11 producers, 3 consumers, and 16 general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. Wolochow.
Vice-Chairman, J. H. Schiele.
Secretary, Chester C. Kelsey.

New Tentative

Committee C-17 recommends that the proposed Specifications for Asbestos-Cement Pressure Pipe, as appended hereto,[1] be accepted for publication as tentative.

Tentatives Continued without Revision

Committee C-17 recommends that the following tentatives be continued without revision, pending further study:

Tentative Specifications for:

Asbestos-Cement Flat Sheets (C 220 – 49 T),
Asbestos-Cement Corrugated Sheets (C 221 – 49 T),
Asbestos-Cement Roofing Shingles (C 222 – 49 T), and
Asbestos-Cement Siding Shingles and Clapboards (C 223 – 49 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee, which consists of 30 members; 22 members returned their ballots, of whom 21 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

HUBERT R. SNOKE,
Chairman.

CHESTER C. KELSEY,
Secretary.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-18

ON

NATURAL BUILDING STONES*

Committee C-18 held two meetings during the year: on November 2, 1951, and on March 28, 1952, both in Washington, D. C. In addition, Subcommittee I, advisory, met on August 17, 1951, in New York City.

The membership now consists of 23 members, of whom 7 are classified as producers, 9 as consumers, and 7 as general interest members. There are also 2 consulting members.

An election of officers was held at the March meeting, at which time the present officers were re-elected for the ensuing two-year term.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Standard Method of Test for Modulus of Rupture of Natural Building Stone **(C 99 – 47)**.[1]—Committee C-18 recommends for immediate adoption the following revisions, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to the letter ballot of the Society:

Section 4.—Change to read as follows:

4. *Test Specimens.*—The specimens shall be approximately 4 by 8 by 2½ in. in size, and three or more shall be prepared for each desired condition of loading. They shall be sawed from the sample and finished by grinding to smooth surfaces. The 4 by 8-in. faces shall be as nearly plane and parallel as practicable. For loading perpendicular to the rift (Note 1) three specimens shall be prepared with the 4 by 8-in. faces parallel to the rift planes (see A_2 in Fig. 1), and for loading parallel to the rift, three specimens shall be prepared with the 4 by 2½-in. faces parallel to the rift (Note 2). When tests are desired on the stone in both the wet and dry condition, six specimens shall be prepared for each direction of loading; that is, three for tests dry, perpendicular to the rift, three for tests wet, perpendicular to the rift, etc.

Section 5.—Change to read as follows:

5. (*a*) *Marking and Measuring Specimens.*—On the 4 by 8-in. face the center line shall be drawn perpendicular to one edge (8 by 2½-in. face) and extended down both edges perpendicular to the 4 by 8-in. face. At a distance of 3.5 in. each way from the center line, two similar sets of lines (span lines, "*a*" in Fig. 1) shall be drawn. Each specimen shall then be marked to indicate the direction of the rift and labeled with suitable numbers or letters for identification in measuring and testing.

(*b*) The dimensions of the cross-section shall be measured on the center line. The width shall be measured to the nearest 0.01 in. and the thickness shall be taken as the average of three measurements to the nearest 0.01 in., one taken at the center and one near each edge.

Section 7.—Change to read as follows:

7. *Procedure.*—The specimen shall be laid flatwise on the supporting knife edges, spaced 7 in. apart and equidistant from the loading knife edges (Note), with all three knife edges parallel. When a load of 10 lb has been applied, the loading shall be stopped and all knife edges made to coincide with the marks on the specimen by centering the specimen under the loading edge and moving the supporting edges under the span marks. The loading shall then be applied at a rate not exceeding 1000 lb per min until failure of the specimen.

NOTE.—When all three knife edges are of the rocker type, care must be taken to adjust all three until the top face of the specimen is horizontal when loaded.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 3.

Section 8.—Add the following paragraph:

(*c*) The following additional information shall be reported:

(*1*) Identification of the sample, including the name and location of the quarry, name and position of the ledge, date when sample was taken, and trade name or grade of the stone,

(*2*) Size and shape of specimens used in the test, and

(*3*) A description of the way in which the specimens were prepared.

Standard Method of Flexure Testing of Slate (Modulus of Rupture, Modulus of Elasticity) (C 120 – 48).[1]—Committee C-18 recommends for immediate adoption the following revision, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Section 3(b).—Change to read as follows:

Roofing Slate.—One 4 by 4-in. specimen, of the thickness of the slate, shall be cut from each of 6 shingles. No part of the specimen shall be cut nearer than one in. to a sheared edge or a nail hole. The direction of the length of the shingle shall be marked on each specimen, and the split faces shall not be resurfaced.

Figure 1.—Delete.

Note 1.—Delete.

Section 5.—Change to read as follows:

5. *Marking and Measuring*.—On structural or electrical slate the center lines shall be ruled with a T-square perpendicular to the edges of the specimens. Likewise, the span lines shall be ruled and parallel to, and 5 in. from, the center lines. On specimens of roofing slate the center lines shall be ruled perpendicular to an edge that is parallel to the length of the shingle. Span lines shall be ruled parallel to, and one in. from, the center lines.

Section 6.—Change to read as follows:

6. *Procedure*.—The testing machine shall be accurate to 1 per cent within the range 100 to 2000 lb. The specimens shall be placed flatwise on knife edges of the type shown in Fig. 1 of the Standard Method of Test for Modulus of Rupture of Natural Building Stone (ASTM Designation: C 99). The load shall be applied at the center of span through a similar knife edge, with the supporting knife edges centered under the span lines. Loads shall be applied at rates not exceeding 1000 lb per min until failure, and the breaking load recorded to the nearest 5 lb.

Note.—Delete.

Sections 9 and 10.—Change to read as follows:

9. *Test Specimens*.—The modulus of elasticity may be determined in conjunction with the modulus of rupture test. For this test on roofing slate it will be desirable to use a specimen 8 in. long.

10. *Procedure*.—The specimen shall be supported and loaded in the same way as for the flexural strength determination, except the roofing slate specimen shall be supported on a six-inch span. Any type of deflectometer capable of reading to 0.001 in. shall be set to measure deflections at mid-span. The loading shall be stopped at each 50-lb increment and the corresponding deflections recorded.

Section 12.—Add the following:

The following information shall be reported: Identification of the sample, including name and location of the quarry, name and position of the ledge, date when sample was taken, and trade name or grade of the slate.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Nomenclature and Definitions (L. W. Currier, chairman).—Additional definitions have been agreed upon in the subcommittee including definitions of soapstone and flagstone. The Dale system of classification of grain size of commercial granites has been agreed upon as an acceptable basis of identification of textural varieties.

Subcommittee III on Test Procedures (D. W. Kessler, chairman).—A comprehensive research report on domestic marbles, developed at Mellon Institute and sponsored by the National Association of Marble Producers, has pointed out that durability based on the gypsum test (ASTM Method C 218 T) does not give sufficient information, and further basic scientific research is necessary in order to establish the relation of structural characteristics of building stone. Further research will be continued at Mellon Institute.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee IV on Specifications (F. S. Eaton, chairman).—An extension of time was granted to the task groups which are considering specifications for granite, roofing slate, marble, and limestone.

This report has been submitted to letter ballot of the committee, which consists of 23 voting members; 20 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. W. CURRIER,
Chairman.

F. S. EATON,
Secretary.

REPORT OF COMMITTEE C-19

ON

STRUCTURAL SANDWICH CONSTRUCTIONS*

Committee C-19 on Structural Sandwich Constructions held two meetings during the year: one meeting was held on June 21–22, 1951, in conjunction with the Annual Meeting at Atlantic City, the second on October 22–23, 1951, at, the National Bureau of Standards Washington, D. C. Since the last report two new members have been elected and one member has resigned. The present committee consists of 60 members with 49 voting members, of whom 23 are classified as producers, 11 as consumers, and 15 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, E. W. Kuenzi.
Vice-Chairman, T. P. Pajak.
Secretary, B. D. Beamish.

NEW TENTATIVE

Committee C-19 recommends that the proposed Tentative Method of Tension Test in Flatwise Plane of Sandwich Constructions appended hereto[1] be accepted for publication as tentative. This recommendation was submitted to letter ballot of the committee and the results were favorable.

The proposed tentative has been submitted for review to Committee E-1 on Methods of Testing.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Mechanical Properties of Basic Materials (R. C. Platow, chairman).—No new tentatives have been prepared in final form during the year, although several methods are under consideration. These are for determining heat distortion, bondability, dimensional stability, and thermal expansion.

Subcommittee II on Mechanical Properties of Basic Sandwich Construction (E. W. Kuenzi, chairman).—A method of tension testing in the flatwise plane has been developed and approved and is being recommended at this time for publication as a tentative as noted earlier in this report. The method of test for flexure is still subject to revision and subsequent approval of the committee.

Subcommittee III on Permanence, Durability and Simulated Service (D. G. Reid, chairman).—No further progress has been made on the development of an outdoor exposure test cubicle design, but this problem is still being worked on. It was generally agreed at the last meeting of the committee that it might be wise to propose a beam-type specimen for exposure at the various ASTM exposure sites. This proposal is also being studied.

Subcommittee IV on Nomenclature and Definitions (J. J. Lamb, chairman).—No new definitions have been developed in the past year.

This report has been submitted to letter ballot of the committee, which consists of 49 voting members; 29 returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. G. H. DIETZ.
Chairman.

R. B. DUNWODY,
Secretary.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-21

ON

CERAMIC WHITEWARE*

Committee C-21 held two meetings in 1951: on April 21 and September 27. There were 15 resignations of individuals, and 8 new memberships were approved. The present voting membership is 39 producers, 11 consumers, and 19 general interest, or a total of 69.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. G. Harman.

Vice-Chairman, J. R. Beam.

Secretary, R. F. Geller.

Members of the Executive Subcommittee at Large, J. H. Koenig and R. Russell, Jr.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (A. S. Watts, chairman).—Several meetings were held during the year at which the present Tentative Definitions C 242 – 50 T were considered, as well as 23 new definitions. As a result, certain of the existing definitions will be continued as tentative, without change; twelve definitions were revised; and new definitions were developed.

Subcommittee II on Tests and Specifications (F. P. Hall, chairman):

A1 on Clays (G. W. Phelps and A. T. Klinefelter, co-chairmen).—This group has developed test methods for sieve analysis, water content, chemical analysis, sampling, and shrinkage. Although the necessary affirmative votes were obtained in a general ballot of the committee, the comments received with the negative votes indicated the advisability of returning the methods to the working group for reconsideration.

A2 on Nonplastics (R. F. Sherwood, chairman).—Consideration of methods for (*a*) chemical analysis of feldspar, flint, talc, pyrophyllite, and nepheline syenite, and (*b*) particle-size determination are being continued.

B on Processing Controls (C. H. Commons, chairman).—A survey on process control in the whiteware industries was made and prepared for publication.

C on Product Tests and Specifications (W. C. Mohr, chairman).—Tentative methods of test for the determination of true specific gravity, modulus of rupture of fired dry-pressed specimens, and linear thermal expansion were developed by this group and submitted to general ballot. Although the necessary affirmative votes were obtained, the methods were returned to the working group for consideration of the many constructive suggestions submitted with the negative votes.

Subcommittee III on Research (C. G. Harman, chairman).—Under the sponsorship of the subcommittee, discussions dealing with various phases of research in the ceramic whiteware field were prepared, of which some have been submitted for publication. New work undertaken consists of: (*1*) Research into the reasons for conflicting results of modulus of rupture tests, (*2*) Studies of the potential usefulness of modulus of elasticity tests, (*3*) Evaluation of test methods for determining the sub-sieve sizes of flint, and (*4*) Organization of a symposium to be held during the 1952 Annual Meeting.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 17-23, 1952.

This report has been submitted to letter ballot of the committee, which consists of 69 voting memberships; 46 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

J. H. KOENIG,
Chairman.

R. F. GELLER,
Secretary.

REPORT OF COMMITTEE C-22

ON

PORCELAIN ENAMEL*

Committee C-22 on Porcelain Enamel held two meetings during the year: one on September 27 and 28, 1951, as guests of the A. O. Smith Corp., Milwaukee, Wis., and one on March 6 and 7, 1952, in Cleveland, Ohio, as a part of the Spring Committee Week.

During the past year four new members were added to the committee and there were three removals. At the present time, the committee consists of 37 members, of whom 32 are voting members, with 17 classified as producers, 5 as consumers, and 10 as general interest.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. N. Harrison.

Vice Chairman, D. G. Bennett.

Secretary, G. H. Spencer-Strong.

Members of Executive Subcommittee at Large: W. A. Deringer, J. H. Gregory.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Research (G. H. McIntyre, chairman).—Two task groups have been appointed and are carrying on investigations on the development and appraisal of thermal shock test (W. N. Harrison, chairman) and an investigation concerning the short- and long-term effect of porcelain enamels on the underlying metals when subjected to elevated temperatures (D. G. Bennett, chairman).

The subcommittee recommended the organization of a symposium on the subject "Porcelain Enamels and Ceramic Coatings as Engineering Materials" to be presented at the 1953 Annual Meeting. A task group was formed to implement the recommendation.

Subcommittee II on Nomenclature (E. E. Howe, chairman).—The subcommittee is continuing work on improvement of the tentative definition of terms.

Subcommittee III on Tests and Specifications (R. F. Bisbee, chairman).—

Sections 1 and 2, Raw Materials and Materials in Process (W. A. Deringer, chairman) have completed the preparation of a revision of the tentative sieve test C 285 - 51 T to include a simplified method of test suitable for enamel plant control operations. A tentative method for the determination of reflectivity should be ready in the near future.

Studies on the development of tentative tests for warpage of enameling iron, the effect of mill-added water composition on porcelain enamel, porcelain enamel consistency, and fusion flow methods are in progress.

Section 3, Finished Products (J. H. Gregory, chairman) has eleven test methods under consideration. A tentative method for the determination of reflectance is ready for letter ballot for Committee C-22 but is being held in abeyance pending cooperative action among Committees C-22, D-1, and E-12. Proposed tentative methods for warpage, gloss, abrasion, and adherence are approaching final stages of preparation.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

This report has been submitted to letter ballot of the committee, which consists of 32 voting members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. N. HARRISON,
Chairman.

G. H. SPENCER-STRONG,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-22 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Method of Test for Sieve Analysis of Wet Milled and Dry Milled Procelain Enamel (C 285 – 51 T) be revised. This recommendation was accepted by the Standards Committee on September 5, 1952, and the revised method appears in the 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE D-1

ON

PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS*

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year: in Atlantic City, N. J., June 18 to 20, 1951, in connection with the 1951 Annual Meeting of the Society, and in Cleveland, Ohio, March 3 to 5, 1952, in connection with the Spring Group Committee Meetings.

At the June, 1951, meeting, R. J. Wirshing, General Motors Corp., presented a paper on "Weathering of Paints," which was illustrated with a group of colored slides.

At the March, 1952, meeting, a Panel Discussion on Printing Inks was held. G. L. Erickson served as chairman, and the panel was made up of George Cramer, Fred Petke, L. H. Sjodahl, and W. C. Walker. The discussion covered the requirements, properties, testing, and manufacturing problems of printing inks as compared to paints.

Committee D-1 will celebrate the 50th anniversary of its founding during the 1952 Annual Meeting of the Society. A special committee consisting of J. C. Moore (chairman), R. H. Crossley, E. W. Fasig, W. A. Gloger, C. C. Hipkins, W. H. Lutz, W. T. Pearce, and C. H. Rose is planning an appropriate program to be held in conjunction with the 50th Anniversary Meeting of ASTM. Highlights of the special events will be a Symposium on Paint[1] and a banquet at which members with records of long service in the committee will be honored.

During the past year, Subcommittee XII on Exterior Exposure Testing of Paints on Wood (W. R. Fuller, chairman) completed its assignment and was placed on an inactive status, with Mr. Fuller named as advisor. Subcommittee XIV on the Electrometric Testing of Films (D. L. Hawke, chairman) was discharged upon its own request.

Cooperative work with the Federation of Paint and Varnish Production Clubs has continued active during the year under the Joint Committee (S. Werthan, chairman). The number of joint standards is now 53, which includes the following methods and specifications approved in the past year by the Standards and Methods of Test Committee of the Federation; both ASTM and Federation numbers are shown:

D 1200 - 52 T (Fed. 40-51), Method of Test for Viscosity of Paints, Varnishes, and Lacquers by the Ford Viscosity Cup,

D 562 - 47 (Fed. 41-51), Method of Test for Consistency of Exterior House Paints and Enamel-Type Paints,

D 821 - 47 (Fed. 42-51), Method of Evaluating Degree of Resistance of Traffic Paint to Abrasion, Erosion, or a Combination of Both, in Road Service Tests,

D 1005 - 51 (Fed. 43-51), Method for Measurement of Dry Film Thickness of Paint, Varnish, Lacquer, and Related Products,

D 1133 - 50 T (Fed. 44-51), Method of Test for Kauri-Butanol Value of Hydrocarbon Solvents,

D 83 - 41 (Fed. 45-52), Specifications for Red Lead,

D 209 - 47 (Fed. 46-52), Specifications for Lampblack,

D 211 - 47 (Fed. 47-52), Specifications for Chrome Yellow and Chrome Orange,

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Issued as ASTM *STP No. 147.*

D 212 - 47 (Fed. 48–52), Specifications for Pure Chrome Green,
D 261 - 47 (Fed. 49–52), Specifications for Iron Blue,
D 476 - 48 (Fed. 50–52), Specifications for Titanium Dioxide Pigments,
D 478 - 49 (Fed. 51–52), Specifications for Zinc Yellow (Zinc Chromate),
D 561 - 46 (Fed. 52–52), Specifications for Carbon Black,
D 656 - 49 (Fed. 53–52), Specifications for Pure Toluidine Red Toner,
D 768 - 47 (Fed. 54–52), Specifications for Yellow Iron Oxide, Hydrated, and
D 963 - 49 (Fed. 55–52), Specifications for Copper Phthalocyanine Blue.

Ten additional ASTM test methods are now under study by the Federation. Similarly, three Federation methods are being considered within Committee D-1. The two organizations are cooperating in the preparation of specifications for mineral spirits.

The Technical Coordinating Committee for the Paint Industry, on which Committee D-1 is represented, has prepared a list of technical problems which deserve the immediate attention of the industry. This list is to be published in the "Official Digest" of the FPVPC.

The Committee on Inter-Committee Relations which is composed of D-1 representatives on other technical committees is continuing its close contact with those committees whose activities are of interest to Committee D-1.

The cooperative work with Committee D-2 on Petroleum Products and Lubricants is being continued. As a result of the close work of D-1 representatives with Committee D-16, specifications for three industrial aromatic hydrocarbons have been prepared for joint sponsorship of Committees D-1 and D-16 on Industrial Aromatic Hydrocarbons.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. T. Pearce.
Vice-Chairman, E. W. Fasig.
Secretary, W. A. Gloger.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meetting, Committee D-1 presented to the Society through the Administrative Committee on Standards the following recommendations. The date following each recommendation is the date of acceptance by the Standards Committee:

Tentative Specifications for:

Asphalt-Base Emulsions for Use as Protective Coatings for Metal (D 1187 - 51 T) (November 26, 1951),
Calcium Carbonate Pigments (D 1199 - 52 T) (May 14, 1952),

Tentative Method of:

Measurement of Dry Film Thickness of Nonmagnetic Coatings of Paint, Varnish, Lacquer, and Related Products Applied on a Magnetic Base (D 1186 - 51 T) (November 26, 1951),
Test for Solvent Tolerance of Amine Resins (D 1198 - 52 T) (April 30, 1952),
Test for Viscosity of Paints, Varnishes, and Lacquers by the Ford Viscosity Cup (D 1200 - 52 T) (May 14, 1952),

Revision of Tentative Methods of:

Testing Drying Oils (D 555 - 51 T) (December 13, 1951),
Testing Varnishes (D 154 - 50 T) (April 30, 1952),

Revision of Tentative Specifications for:

Venetian Red (D 767 - 50 T) (April 30, 1952),

Revision and Reversion to Tentative of Standard Method of:

Test for Specific Gravity of Pigments (D 153 - 39) (May 14, 1952),
Test for Mass Color and Tinting Strength of Color Pigments (D 387 - 36) (May 14, 1952),

Withdrawal of Standard Methods of:

Testing Drying Oils (D 555 - 47) (December 13, 1951), and

Withdrawal of Tentative Method of:

Test for Heat Bodying Rate of Drying Oils (D 967 - 48 T) (December 13, 1951).

Those recommendations accepted during 1951 appear in the 1951 Supplement to Book of ASTM Standards, Part 4.

PROPOSED METHOD TO BE PUBLISHED AS INFORMATION

The committee recommends for publication as information the Proposed Method of Test for Flash Point of Volatile Solvents by the Tag Open-Cup Apparatus as appended hereto.[2]

NEW TENTATIVES

The committee recommends for publication as tentative the following seven methods of test, as appended hereto:[3]

Tentative Methods of Test for:

Common Properties of Certain Pigments,
Color of Clear Liquids, Using the Platinum-Cobalt Scale,
Temperature-Change Resistance of Clear Nitrocellulose Lacquer Films Applied to Wood,
Fineness of Dispersion of Pigment Vehicle Systems,
Crushing Resistance of Glass Spheres,
Sieve Analysis of Glass Spheres, and
Measurement of Wet Film Thickness of Paint, Varnish, Lacquer, and Related Products.

REVISION OF TENTATIVE

Committee D-1 recommends that the Tentative Method of Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding (**D 969 – 48 T**)[4] be revised as follows:

Apparatus 2(b).—Revise the heading "Test Panel" to read: "Test Panel for Coal-Tar Substrate." Delete the bracketed word "(Note)" immediately following the word "felt." Insert an additional paragraph after (*b*) to read as follows: "(*c*) *Test Panel for Asphalt Substrate.*—A 5 by 10-in. piece cut from a standard roll of 15-lb asphalt-saturated felt (Note)."

NOTE.—In line 2 of the explanatory text delete the word "coal-tar" and in line 4 between the numeral "2" and the word "when," insert the phrase "on the coal tar, and the lesser bleeding necessary for a rating of 9–7 on asphalt." In the last sentence delete the words "coal-tar felt" and substitute the words "test panels."

There is no change in the composition table.

Procedure 4.—In the last line of Paragraph (*b*) and the fifth line of Paragraph (*d*) delete the words "tarred felt" and substitute the words "test panels."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following four standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Method of Test for No-Pick-Up Time of Traffic Paints (**D 711 – 51**),[4] revise as follows:

Fig. 1.—Replace "Toy wheel with $\frac{3}{4}$-in. rubber tire," by "Coaster wagon wheel with $\frac{5}{8}$-in. rubber tire."

Footnote.—Add a new footnote to read as follows: "A source of the wheel is Montgomery Ward Co., No. R48B 5552M, as listed on page 694 of their 1951 Spring and Summer Catalogue."

Definitions of Terms Relating to Paint, Varnish, Lacquer, and Related Products (**D 16 – 51**).[5]—Revise by the addition of the following new definition of printing ink and revised definitions of the terms bleeding, drier, pigment, pigment volume, and vehicle.

Printing Ink.—A colored or pigmented liquid or paste composition that dries to a solid film after application as a thin layer by printing machinery.

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[2] See p. 318.

[3] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 4.

[4] 1949 Book of ASTM Standards, Part 4.

[5] 1951 Supplement to Book of ASTM Standards, Part 4.

Bleeding.—The diffusion of coloring matter through a coating from the substrate; also, the discoloration arising from such diffusion.

In the case of printing ink, the spreading or running of a pigment color by the action of a solvent such as water or alcohol.

Drier.—A composition which accelerates the drying of oil, paint, printing ink, or varnish. Driers are usually metallic compositions and are available in both solid and liquid forms.

Pigment.—The fine solid particles used in the preparation of paint or printing ink, and substantially insoluble in the vehicle. Asphaltic materials are not pigments except when they contain substances substantially insoluble in the vehicle in which they are used.

Pigment Volume.—The percentage of volume of pigment in the nonvolatile portion of a paint or printing ink as calculated from bulking value and composition data. The letters PV are commonly used as an abbreviation.

Vehicle.—The liquid portion of paint or printing ink. Anything that is dissolved in the liquid portion of a paint or printing ink is a part of the vehicle.

Methods of Chemical Analysis of Dry Cuprous Oxide and Copper Pigments (**D 283 – 51**).[4]—Revise as follows:

Section 5(c).—Change the formula to read as follows:

Total reducing power as cuprous oxide, per cent

$$= \frac{(AB - CD) \times 0.07157 \times 100}{E}$$

At the end of Section 5 (*c*), add "*E* = grams of sample used."

Section 9.—Change the formula to read as follows:

Cupric oxide, per cent =

$$1.252\ (C - B) - 1.112\ D$$

Section 14 (d).—Change the formula to read as follows:

Chlorides, per cent

$$= \frac{\text{g of AgCl} \times 0.247}{\text{g of sample} \times 0.1} \times 100$$

Section 14 (f).—Change the formula to read as follows:

Sulfates, per cent

$$= \frac{\text{g of BaSO}_4 \times 0.412}{\text{g of sample} \times 0.1} \times 100$$

Methods of Test for Phthalic Anhydride Content of Alkyd Resins and Resin Solutions (**D 563 – 49**).[4]—Revise as follows:

Section 1.—Add to the first sentence the words, "including those containing styrene."

Section 3 (b).—Change the phrase "40 g of reagent grade KOH" to read "66 g of reagent grade KOH." Delete Paragraph (*d*) including the word "(Note)" at end of sentence. Do not delete the Note.

Insert a new Paragraph (*d*) to read as follows:

(*d*) *Alcohol-Benzene Wash Solution.*—Mix 3 volumes of benzene with 1 volume of absolute ethyl alcohol (Note)."

Section 4.—In the second sentence of Paragraph (*a*), change "10" to "150 ml of benzene." In the third sentence change "150 ml of alcoholic KOH" to "60 ml of alcoholic KOH."

In the first sentence of Paragraph (*b*), change "alcohol-ether wash solution" to "alcohol benzene wash solution." Delete the last sentence.

In Paragraph (*c*) begin the first sentence with "When cool." In the fourth line, first sentence, change "alcohol-ether" to "alcohol-benzene." Also make this same change in the second sentence.

ADOPTION OF TENTATIVES AS STANDARDS

Committee D-1 recommends that the following seven tentatives be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Raw Castor Oil (D 960 – 48 T),
Secondary Butyl Acetate (85 to 88 per cent Grade) (D 966 – 48 T),
Secondary Butyl Alcohol (D 1007 – 49 T),

Tentative Methods of:

Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products (D 609 - 50 T),
Test for Total Nitrogen in Resins for Surface Coatings (D 1013 - 49 T),
Test for Total Chlorine in Polyvinyl Chloride Polymers and Copolymers Used for Surface Coatings (D 1156 - 51 T), and
Test for Night Visibility of Traffic Paints (D 1011 - 49 T), with the inclusion of a reference to the paper by T. E. Shelbourne, "Comparison of Reflectance Readings of Traffic Paints," in the April, 1951, ASTM BULLETIN.

WITHDRAWAL OF STANDARDS

The committee recommends that the following three standards be withdrawn for the following reasons: the first method of test has been incorporated into a new tentative; the materials covered by the next two specifications are no longer being manufactured for industrial use:

Method of Test for Alkalinity or Acidity of Pigments (D 278 - 31),
Specifications for Butyl Propionate (90 to 93 per cent Grade) (D 320 - 40),
Specifications for Ethyl Lactate (Synthetic) (D 321 - 40).

REAFFIRMATION OF STANDARDS

Committee D-1 recommends the reaffirmation of the following 26 standards which have been published for six years or longer without revision:

Standard Methods of:

Test for Coarse Particles in Pigments, Pastes, and Paints (D 185 - 45),
Chemical Analysis of White Linseed Oil Paints (D 215 - 41),
Chemical Analysis of Dry Red Lead (D 49 - 44),
Test for Hygroscopic Moisture (and Other Matter Volatile Under the Test Conditions) in Pigments (D 280 - 33),
Analysis of Barium Sulfate Pigments (D 715 - 45),
Analysis of Mica Pigment (D 716 - 45),
Analysis of Aluminum Silicate Pigment (D 718 - 45),
Test for Spectral Characteristics and Color of Objects and Materials (D 307 - 44),
Test for Relative Dry Hiding Power of Paints (D 344 - 39),
Test for Relative Dry Hiding Power of White Pigments in a Linseed Oil Vehicle (D 406 - 39),
Conducting Road Service Tests on Traffic Paint (D 713 - 46), and
Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus (D 522 - 41).

Standard Specifications for:

Ethyl Acetate (85 to 88 per cent Grade) (D 302 - 33),
Normal Butyl Acetate (88 to 92 per cent Grade) (D 303 - 40),
Butanol (Normal Butyl Alcohol) (D 304 - 45),
Amyl Acetate (Synthetic) (85 to 88 per cent Grade) (D 318 - 39),
Amyl Alcohol (Synthetic) (D 319 - 40),
Acetone (D 329 - 33),
Ethylene Glycol Monobutyl Ether (D 330 - 35),
Ethylene Glycol Monoethyl Ether (D 331 - 35),
Acetate Ester of Ethylene Glycol Monoethyl Ether (95 to 96 per cent Grade) (D 343 - 35),
Amyl Acetate Made with Fusel Oil (85 to 88 per cent Grade) (D 554 - 39),
Dibutylphthalate (D 608 - 43),
Isopropyl Acetate (D 657 - 44),
Methyl Ethyl Ketone (D 740 - 46), and
Isopropyl Alcohol (D 770 - 46).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following seven tentatives be continued as tentative without revision:

Tentative Method of:

Test for Heptane Number of Hydrocarbon Solvents (D 1132 - 50 T),
Test for Kauri-Butanol Value of Hydrocarbon Solvents (D 1133 - 50),
Test for Nitrocellulose Diluting Power of Hydrocarbon Solvents (D 1134 - 50 T),
Chemical Analysis of Yellow, Orange, and Green Pigments Containing Lead Chromate and Chromium Oxide Green (D 126 - 50 T),

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Chemical Analysis of Zinc Dust (Metallic Zinc Powder) (D 521 - 50 T),
Chemical Analysis of Blue Pigments (D 1135 - 50 T), and
Test for Ester Value of Tricresyl Phosphate (D 268 - 49 T).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Drying Oils (Francis Scofield, chairman) completed the extensively revised Tentative Methods of Testing Drying Oils (D 555 - 51 T). Work is continuing on methods for sampling drying oils, total iodine number, and foots. Specifications for safflower oil are being drawn up, and the work on spectrophotometric analysis is being conducted in cooperation with the Spectroscopy Committee of the American Oil Chemists' Society.

Subcommittee III on Bituminous Emulsions (R. H. Cubberley, chairman) prepared the Tentative Specifications for Asphalt-Base Emulsions for Use as Protective Coatings on Metal (D 1187 - 51 T) which were accepted by the Administrative Committee on Standards on November 26, 1951. Revision of the Tentative Methods of Testing Bituminous Emulsions for Use as Protective Coatings for Metal (D 1010 - 49 T) is under consideration, as well as further work on drafting Proposed Specifications for Coal-Tar Base Emulsions for Use as Protective Coatings on Metal.

Subcommittee IV on Traffic Paint (W. G. Vannoy, chairman).—Cooperative tests are being continued to develop accelerated testing procedures for suspension and durability of traffic paints, and on the clarity, chemical stability, and wettability of glass spheres.

Subcommittee V on Volatile Solvents for Organic Protective Coatings (M. B. Chittick, chairman) is bringing to a conclusion its work on a new proposed method for the determination of viscosity reduction power of hydrocarbon solvents and on proposed and revised specifications for mineral spirits, which latter have been developed jointly with the Federation of Paint and Varnish Production Clubs. The subcommittee is proceeding to develop a method of test for determining evaporation rates of solvents and thinners, and is continuing its cooperative work with Committee D-2 on distillation, flash point, and copper corrosion.

Subcommittee VI on Definitions (G. G. Sward, chairman) prepared the new definition for "Printing Ink" and a printing ink definition of "Bleeding," which it recommends be added to the Definition of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 - 51). It also recommends the insertion of the phrase "printing ink" in the definitions for "Drier," "Pigment," "Pigment Volume," and "Vehicle."

The subcommittee recommends a change in the practice of publishing tentative definitions. Instead of a separate tentative, it recommends that the tentative definitions appear in their proper alphabetical order in Standard D 16, with a symbol to identify them as tentative. In this way, users will find the tentative definitions more easily.

Subcommittee VII on Accelerated Tests for Protective Coatings (R. H. Sawyer, chairman).—Work is under way on a description of polishing cloth, a test for cleanliness of panel surfaces, a water fog test, and a method of rating blisters. A program for a cooperative study of laboratory exposure machines has been organized, and it is planned to request the assistance of Committee E-1 on Methods of Testing in this work.

Subcommittee VIII on Methods of Chemical Analysis of Paint Materials (C. Y. Hopkins, chairman) prepared the proposed Tentative Methods of Test for Common Properties of Certain Pigments, appended hereto,[7] and therefore has recommended that the Method of Test for Alkalinity or Acidity of Pigments (D 278 – 31) be withdrawn, because this test has been incorporated in the new proposed method. Work is proceeding on the revision of methods of analysis of titanium pigments and of white lead pigments in the Method of Chemical Analysis of White Pigments (D 34 – 51 T).

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[7] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 4.

Subcommittee IX on Varnish (J. C. Weaver, chairman) has in preparation a revision of the Standard Specifications for Liquid Driers (D 600 – 43) to cover concentrated driers of commerce. Work is also under way to improve the procedures used in the Standard Methods of Testing Liquid Driers (D 560 – 47). Work on the exterior durability of varnishes is being brought to a conclusion, and a test method is being prepared. A program of study of the abrasion resistance of floor varnishes has been initiated, and two new working groups, on skinning, and on rosin determination, have been organized.

Subcommittee X on Optical Properties (W. C. Granville, chairman) has undertaken a critical review of the Standard Method of Test for Tinting Strength of White Pigments (D 332 – 36). Results of cooperative tests on the Hunter multipurpose reflectometer will be published and will serve as a basis for redrafting the earlier proposed method on color difference. Work is continuing on a revised proposed method for determining hiding power and on the consolidation of proposed gloss methods. Cooperative work has been started with Committees C-22 on Porcelain Enamel and E-12 on Appearance to revise the Method of Test for Daylight 45 deg, 0 deg Luminous Directional Reflectance of Paint Finishes (D 771 – 47) to meet the combined requirements of Committees D-1 and C-22.

Subcommittee XI on Resins (C. F. Pickett, chairman) prepared the revision of the Methods of Test for Phthalic Anhydride Content of Alkyd Resins and Resin Solutions (D 563 – 49) which allows the method to be used also for alkyd resins containing styrene, and is recommended for immediate adoption as standard. Work on two new proposed tentative methods is being brought to a conclusion: a method for the determination of the apparent free phenol in phenolic resins, and a foil method for the determination of nonvolatile matter in heat-stable resin solutions. Round-robin tests are in progress to extend the foil method to heat-sensitive resins, on determination of resin solution viscosities and on softening point by the ring- and ball apparatus. Specifications for glycerine are being drawn up with the assistance of the major glycerine producers.

Subcommittee XIII on Shellac (C. C. Hartman, chairman) is engaged in the revision of the Specifications for Sampling and Analysis of Shellac (D 29 – 40). New methods for the determination of the color of lac resin to replace the Tentative Method of Test for Color of Orange Shellac (D 29 – 41 T) and for determining polymerized bodies in lac resin, are being developed. The subcommittee has worked closely with the subcomittee of Technical Committee 50 on Lac Resins of the International Standards Organization, on proposed specifications for orange shellac, seedlac, and dry bleached shellac.

Subcommittee XV on Specifications for Pigments Dry and in Oil When Marketed in That Form (C. L. Crockett, chairman) is bringing to a conclusion its work on revising Specifications for Magnesium Silicate Pigment (D 605 – 42). The Specification for Pure Linseed Oil Putty for Glazing (D 317 – 33) will be revised to include the new calcium carbonate specifications.

Subcommittee XVI on Printing Inks (M. C. Rogers, chairman) is bringing to a conclusion its work on its first proposed method of test of fineness of grind. It cooperated in the preparation of the new definitions for "printing ink" and "bleeding," and in the revisions of several definitions to include "printing ink," as mentioned earlier in this report. Six groups are conducting work on a review of available test methods, rub-proofness, rheology, drying time, and ink-paper relationships. New groups have been organized to work on density and tinting strength.

Subcommittee XVII on Flash Point (A. L. Brown, chairman) is actively cooperating with the Manufacturing Chemists Association and ASTM Committees D-2 on Petroleum, and D-8 on Bituminous Waterproofing and Roofing Materials in the drafting of a Tag Open-cup test method. A Proposed Method of Test for Flash Point of Volatilc Solvents by the Tag Open-Cup Apparatus is published as information in the Appendix to this report.[2] Cooperative work is also being conducted with other organizations interested in flash point test methods.

Subcommittee XVIII on Physical Properties of Materials (M. R. Euverard, chairman) is finishing its work on a new method for measurement of wet film thickness. Under active consideration are methods of test for oil absorption of pigments, consistency of pastes, adhesion, hardness of organic films, permeability, fire retardency, and flow properties.

Subcommittee XXV on Cellulosic Coatings and Related Materials (F. H. Lang, chairman) cooperated with Committee D-16 in preparing the consolidated specifications for three industrial aromatic hydrocarbons which are recommended for immediate adoption as joint standards. The subcommittee is engaged in rewriting Methods of Sampling and Analysis of Lacquer Solvents and Diluents (D 268 - 49) and Methods of Testing Nitrocellulose Clear Lacquers and Lacquer Enamels (D 333 - 40), and is further cooperating with the Joint D-1-D-2 Committee on Distillation.

Subcommittee XXIX on Painting of Metals (A. J. Eickhoff, chairman) has received approval to proceed with the preparation of a set of colored photographic standards intended to be a part of the comprehensive specifications for standards of ferrous surfaces for painting. A specification for the preparation of aluminum surfaces for painting is also being prepared.

This report has been submitted to letter ballot of the committee, which consists of 343 voting members; 173 members returned their ballots, of whom 163 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. T. PEARCE,
Chairman.

C. H. ROSE,
Secretary.
WALTER GLOGER,
Assistant Secretary.

APPENDIX

PROPOSED METHOD OF TEST FOR FLASH POINT OF VOLATILE SOLVENTS BY THE TAG OPEN-CUP APPARATUS[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) This method describes a test procedure for the determination of open-cup flash points of volatile flammable materials having flash points below 175 F.

(*b*) This method, when applied to paints and resin solutions which tend to skin over or which are very viscous, gives less reproducible results than when applied to solvents.

(*c*) A value in excess of 80 F by this method has been established by the U. S. Interstate Commerce Commission as the minimum value for classifying liquids as nonflammable. Materials having a flash point below that value must be identified with an ICC Red Label for interstate shipment by common carrier within the USA.[3]

Outline of Method

2. The sample is placed in the cup of a Tag Open Tester, and heated at a slow but constant rate. A small test flame is passed at a uniform rate across the cup at specified intervals. The flash point is taken as the lowest temperature at which application of the test flame causes the vapor at the surface of the liquid to ignite.

Apparatus

3. (*a*) *Flash Tester.*—Tag Open-Cup Tester (Fig. 1) as described in detail in the Supplement.

(*b*) *Shield.*—As described in detail in the Supplement.

(*c*) *Thermometer.*—For flash points above 40 F, use the ASTM Tag Closed Tester Thermometer, range of +20 to +230 F, in 1 F divisions, and conforming to thermometer 9F of ASTM Standard E 1.[4] For flash points below 40 F, use ASTM Tag Closed Tester, Low Range, thermometer 57F.

NOTE 1.—The original Tag Open Cup Thermometer is a permissible alternate. It is calibrated to −20 F.

Procedure

4. (*a*) Place the tester on a solid table free of vibration, in a location free of perceptible draft, and in a dim light.

(*b*) Run water, brine, or water-glycol solution into the copper bath to a predetermined level, which will fill the bath to $\frac{1}{8}$ in. below the top when the cup is in place.

(*c*) Firmly support the thermometer vertically halfway between the center

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

This proposed method is based on the Manufacturing Chemists' Association Draft for Flash Point Determination of Liquids for Classification under ICC Regulations by Tagliabue Open Cup.

[2] Published as information June, 1952.

[3] For details of ICC shipping regulations, see *Tariff 8*, issued March 15, 1951, by H. A. Campbell, agent, 30 Vesey St., New York 7, N. Y., publishing Interstate Commerce Commission Regulations for Transportation of Explosives and other Dangerous Articles by Land and Water in Rail Service and by Motor Vehicle (highway and water) including Specifications for Shipping Containers. (Regulations for transportation in rail express and rail baggage services are also included therein for information.)

[4] 1951 Supplement to Book of ASTM Standards, Part 5.

and edge of the cup on a diameter at right angles to the guide wire, or on a diameter passing through the center of the cup and the pivot of the taper. Place so that the bottom of the bulb is $\frac{1}{4}$ in. from the inner bottom surface of the cup.

(*d*) Fill the glass cup with the sample liquid to a depth just $\frac{1}{8}$ in. below the edge, as determined by the leveling device.

(*e*) Place the guide wire or swivel device in position, and set the draft shield around the tester so that the sides form right angles with each other, and the tester is well toward the back of the shield.

(*f*) If a guide wire is used, the taper, when passed, should rest lightly on the wire, with the end of the jet burner just clear of the edge of the guide wire. If the swivel type holder is used, the horizontal and vertical positions of the jet are so adjusted that the jet passes on the circumference of a circle, having a radius of at least 6 in., across the center of the cup at right angles to the diameter passing through the thermometer, and in a plane $\frac{1}{8}$ in. above the upper edge of the cup.

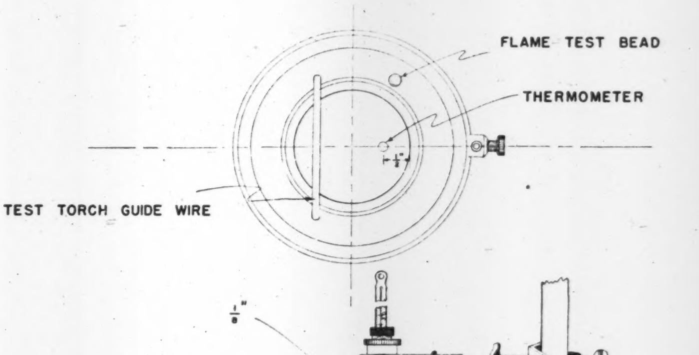
FLAME TEST BEAD
THERMOMETER
1/4"
TEST TORCH GUIDE WIRE
1/8"
TEST TORCH GUIDE WIRE
GLASS TEST CUP
FLAME TEST BEAD
SAMPLE
2 1/4"
3 1/2"
1/4"
BATH
2 13/16"
7 1/8"
BURNER

FIG. 1.—Tag Open-Cup Flash Tester.

The taper should be kept in the "off" position, except when the flame is applied.

(*g*) Light the ignition flame and adjust it to form a flame $\frac{3}{32}$ to $\frac{5}{32}$ in. in diameter.

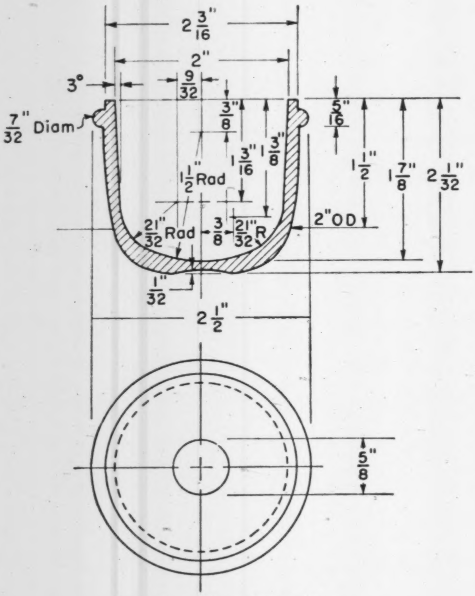

FIG. 2.—Glass Test Cup.

(*h*) Place the heater flame under the center of the bath, and adjust it so that the temperature of the sample increases at a rate of 2 ± 0.5 F per min.

NOTE 2.—With viscous materials, this rate of heating cannot always be obtained.

Initial Test

5. Determine an approximate flash point by passing the taper flame across the sample at intervals of 2 F. The time required to pass the ignition flame across the surface of the sample should be about 1 sec.

NOTE 3.—Remove bubbles from the surface of the sample liquid before starting a determination.

NOTE 4.—When determining the flash-point of viscous liquids and those liquids which tend to form a film of polymer, etc., on the surface, the surface film should be disturbed mechanically each time before the taper flame is passed.

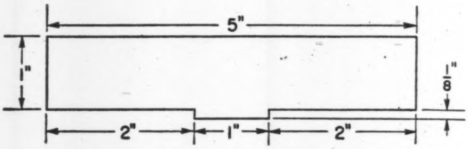

FIG. 3.—Leveling Device for Adjusting Liquid Level in Test Cup.

Repeat Test

6. Repeat the procedure by cooling a *fresh* portion of the sample, the glass cup, the bath solution, and the thermometer at least 20 F below the approximate flash-point. Resume heating, and pass the taper flame across the sample at two intervals of 5 F and then at intervals of 2 F until the flash-point occurs.

SUPPLEMENT

APPARATUS

A1. The Tag Open-Cup Tester is illustrated in Fig. 1. It consists of the following parts, which must conform to the dimensions shown, and have the additional characteristics as noted:

(*a*) *Copper Bath,* preferably equipped with a constant level overflow so placed as to maintain the bath liquid level $\frac{1}{8}$ in. below the rim of the glass cup.

(*b*) *Thermometer Holder.*—Support firmly with ring stand and clamp.

(*c*) *Glass Test Cup* (Fig. 2), of molded clear glass, annealed, heat-resistant, and free from surface defects.

(*d*) *Leveling Device,* or guide, for proper adjustment of the liquid level in the cup (Fig. 3). This shall be made of No. 18-gage polished aluminum, with a projection for adjusting the liquid level when the sample is added to exactly $\frac{1}{8}$ in. below the level of the edge or rim of the cup.

(*e*) *"Micro," or Small Gas Burner* of suitable dimensions for heating the bath. A screw clamp may be used to help regulate the gas.

(*f*) *Ignition Taper,* which is a small, straight, blow-pipe type gas burner. The test flame torch prescribed in the Standard Method of Test for

Flash and Fire Points by Means of Open Cup (ASTM Designation: D 92)[4] is satisfactory.

(*g*) Alternate methods for maintaining the ignition taper in a fixed horizontal plane above the liquid may be used, as follows:

(*1*) *Guide Wire*, $\frac{3}{32}$ in. in diameter and $3\frac{1}{2}$ in. in length, with a right angle bend $\frac{1}{2}$ in. from each end. This wire is placed snugly in holes drilled in the rim of the bath so that the guide wire is $\frac{5}{8}$ in. from the center of the cup and resting on the rim of the cup.

NOTE 5.—Two guide wires located $\frac{3}{8}$ and $\frac{7}{8}$ in., respectively, from the center of the cup and parallel to each other is a permissible alternate.

(*2*) *Swivel-Type Taper Holder*, such as is used in ASTM Method D 92. The height and position of the taper is fixed by adjusting the holder on a suitable ring-stand support adjacent to the flash cup.

(*h*) *Draft Shield*, consisting of two rectangular sheets of noncombustible material, 24 by 28 in., are fastened together along the 28-in. side, preferably by hinges. A triangular sheet, 24 by 24 by 34 in., is fastened by hinges to one of the lateral sheets (to form a top when shield is open). The interior of the draft shield shall be painted a flat black.

REPORT OF COMMITTEE D-2

ON

PETROLEUM PRODUCTS AND LUBRICANTS*

In the interest of brevity, this Report of Committee D-2 on Petroleum Products and Lubricants is confined to the recommendations of the committee. A separate report describing the activities of the committee for the year preceding the Golden Jubilee Meeting in June, 1952, and the program of the committee for the year beginning in June, 1952, will be published in the ASTM BULLETIN.

PROPOSED METHODS AND OTHER MATERIAL TO BE PUBLISHED AS INFORMATION

Technical Committees and Research Divisions of Committee D-2 have submitted the following proposed methods of test and supporting data which are recommended for publication as information as appended to this report:[1]

Appendix I. Supporting data for the adoption of the CFR−48 Crankcase as optional equipment for use with methods of test contained in the "ASTM Manual of Engine Test Methods for Rating Fuels."[2]

Appendix II. Test for API Gravity of Petroleum and its Products by Hydrometer.

Appendix III. Test for Specific Gravity of Petroleum and its Products by Hydrometer.

Appendix IV. Test for Hydrocarbon Types in Jet Propulsion Fuels, Fluorescent-Indicator Adsorption (FIA) Method.

Appendix V. Test for Water in Petroleum and Bituminous Products. This method is a proposed revision of the Standard Method of Test for Water in Petroleum Products and other Bituminous Materials (D 95 – 46).[3]

Appendix VI. Polarographic Determination of Tetraethyllead in Gasoline.

Appendix VII. Test for Tensile Strength of Paraffin Wax.

Appendix VIII. Manometric Method with Null Pressure Transmitter for Vapor Pressure Test of Petroleum Products. This method is intended eventually to be appended to the Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 – 49).[3]

Appendix IX. Test for Oil Content of Petroleum Waxes (see Appendix IV, 1951 Report of Committee D-2).[3a]

NEW TENTATIVES

Committee D-2 recommends that the following seven methods of test be accepted for publication as tentative:

Tentative Definition and Specifications for:

Tractor Fuels[4] (see Appendix VIII, 1950 Report of Committee D-2).[4a]

Tentative:

ASTM-IP Petroleum Measurement Tables.[5]

Tentative Methods of Test for:

Calibrating Liquid Containers, Section A—Upright Tanks.[5]

Analysis of Calcium and Barium Petroleum Sulfonates. This method was published in Appendix XI, 1948 Report of Committee D-2,[5a] and has been further revised as appended hereto.[6]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] See pp. 344–383.

[2] 1952 Edition of ASTM Manual of Engine Test Methods for Rating Fuels.

[3] 1949 Book of ASTM Standards, Part 5.

[3a] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 316 (1951).

[4] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 5.

[4a] *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 311 (1950).

[5] Issued as a separate publication.

[5a] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 367 (1948).

[6] The revised method was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 5.

Measurement of Density and Specific Gravity of Liquids to the Fifth Place (Bingham Pycnometer Method) (see Appendix II, 1951 Report of Committee D-2).[7] The method has been reviewed and is now recommended for publication as tentative with the following change in scope:

Scope.—1. This method is intended for the measurement of the density of pure hydrocarbons or petroleum distillates boiling between 194 and 230 F (90 and 110 C) that can be handled in a normal fashion as a liquid at the specified test temperatures of 68 and 77 F (20 and 25 C). The method was developed especially for the reference fuels *n*-heptane and *iso*octane and is designed to provide values having an accuracy of 0.00004 g per ml.

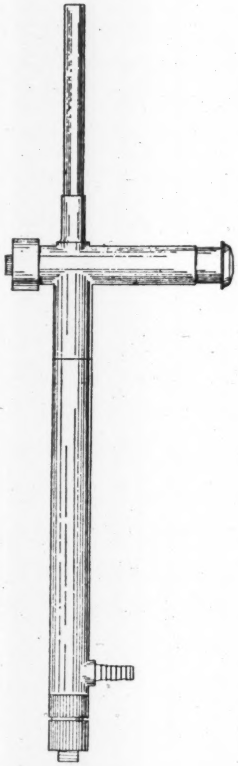

FIG. 1.—Thermometer Holder.

Measurement of Refractive Index and Refractive Dispersion of Hydrocarbon Liquids (see Appendix IV, 1950 Report of Committee D-2).[8] The method has been reviewed and is recommended for publication as tentative with the following changes:

Section 4(c).—Revise to read as follows:

"*(c) Thermometer.*—ASTM Saybolt thermometers 17F - 51 or 17C - 51 having range of 66 and 80 F and 19 to 27 C and conforming to ASTM Standard E 1 shall be used. The thermometer shall be used in an approved holder,[9] such that almost total immersion (not more than 0.2 F emergent stem) is obtained, and reading to 0.02 F (0.01 C) is possible."

New Figure 1.—Add the accompanying Fig. 1 as a new Fig. 1.

Mercaptan Sulfur in Jet Fuels (Color-Indicator Method). The method, as appended hereto,[10] is a modification of Method 520.4, dated June 20, 1950, and published in the United States Federal Stock Catalog VV-L-791d.

REVISION OF TENTATIVES

Committee D-2 recommends revision of the following twenty-three tentatives, as indicated:

D 439 - 50 T,[11] Specifications for Gasoline, revise as follows:

Appendix.—Replace the first paragraph under "Octane Number" with the following four paragraphs:

"There are two recognized laboratory engine test methods for evaluating the anti-knock quality of motor fuels, namely, the Research Method and the Motor Method. The results of these tests of a fuel may generally be translated into approximate field performance, provided information is available on the equipment in which the fuel is to be used and the conditions of operation. However, there are exceptions, so that hard and fast rules cannot be defined and the user must be guided by direct experience as to which method or combination of methods apply to his particular set of conditions. For most equipment, driven in conventional manner, the Research Method usually provides the better guide as to performance and, for this reason, is the method selected for establishing the octane number values in Specifications D 439. The following paragraphs define the two methods more specifically and describe their significance as applied to various kinds of equipment and operating conditions.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 303 (1951).

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 284 (1950).

[9] An improved type holder may be purchased from Bausch & Lomb Optical Co., Rochester, N. Y.

[10] The tentative method was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 5.

[11] 1950 Supplement to Book of ASTM Standards, Part 5.

"The Research octane number is determined by a method which measures anti-knock performance under mild operating conditions—that is, under conditions of relatively low inlet mixture temperature and relatively low engine speeds. It is indicative of fuel anti-knock performance in full-scale engines operating at wide open-throttle and low-to-medium engine speeds. In practice, these conditions would exist for most passenger cars and light-duty commercial vehicles during period of full-throttle operation for all but the most severe conditions which might be encountered, such as accelerating to pass another vehicle at high car speed.

"The Motor octane number is determined by a method which measures anti-knock performance under more severe operating conditions than is employed in the Research method—that is, under conditions of relatively high inlet mixture temperature and at relatively high engine speeds. It is indicative of fuel anti-knock performance in full-scale engines operating at wide-open-throttle and high-engine speeds. In practice, these conditions would exist for many passenger cars and light-duty commercial vehicles during periods of power accelerations at higher road speeds, such as in passing vehicles, or on hills. It would apply to many commercial heavy-duty vehicles during any period of high-power output.

"For many vehicles, such as those having a transmission arrangement which limits the full throttle minimum engine speed to values falling between the low- and high-speed ranges mentioned above, the anti-knock quality of a fuel may best be judged by some value intermediate between its Research and Motor octane numbers."

Footnote "b".—Change the second sentence to read: "See Appendix, Octane Number, for discussion of Research and Motor octane numbers."

Table I.—Revise the octane number column in Table I to read as follows:

Present Motor Method Octane Number, min.	Proposed Research Method Octane Number,[b] min.
70 or 77[b]	78 or 85[c]
70 or 77[b]	78 or 85[c]
50[b]	[d]

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[b] Same as present footnote "*b*."

[c] The numerical values shown are minimum values currently encountered in service stations. The lower value is representative of regular-price gasolines, and the higher value of premium-price gasolines. For more detailed information on current levels for both research and motor octane numbers, as well as for other characteristics of motor gasoline, reference is made to the series of semi-annual reports, issued as Reports of Investigation (R.I.) by the U. S. Bureau of Mines and entitled "National Motor Gasoline Survey." (Values reported in Table I are derived from the Winter 1951–1952 Survey (R.I. 4901)).

[d] The information available does not permit designation of a minimum research octane number value for Type C gasoline.

Reletter the present footnotes "*c*" to "*g*" as "*e*" to "*i*."

Section 6 (*c*).—Change the word "Motor" to "Research," and the ASTM Designation from "D 357" to "D 908."

D 910 – 51 T.[12] Specifications for Aviation Gasolines, revise as follows:

Section 1.—Change Paragraph (*b*) under "Scope" to read as follows:

"(*b*) These specifications define specific types of aviation gasolines for civil use. They do not include all gasolines satisfactory for reciprocating aviation engines. Certain equipment or conditions of use may permit a wider, or require a narrower, range of characteristics than is shown by these specifications."

D 94 – 48 T.[3] Test for Saponification Number of Petroleum Products by Color-Indicator Titration, revise as follows:

Section 1.—Change to read as follows:

"1. *Scope*.—This method of test is intended for determining the amount of constituents in petroleum products that will easily saponify under the conditions of the test. Since compounds of sulfur, phosphorus, the halogens, and certain other elements which are sometimes added to petroleum products also consume alkali and acids, the results obtained indicate the effect of these extraneous materials in addition to the saponifiable material present. Results on products containing such materials, on used internal-combustion-engine crank-case oils, and on used turbine oils must be interpreted in this respect.

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[12] 1951 Supplement to Book of ASTM Standards, Part 5.

"NOTE 1.—The materials referred to above which are not normally considered saponifiable matter include inorganic or certain organic acids, most nonalkali soaps, etc."

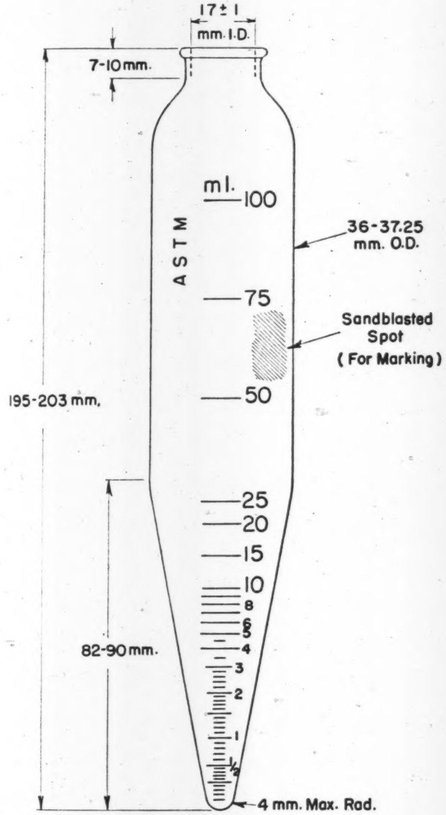

FIG. 2.—ASTM Cone-Shaped Centrifuge Tube.

D 96 – 50 T.[11] Test for Water and Sediment by Means of Centrifuge, revise as follows:

Section 2 (a).—Change to read as follows: "2 (*a*) *Centrifuge*, capable of whirling two or more filled centrifuge tubes at a speed which can be controlled to give a relative centrifugal force (rcf) of between 500 and 700 at the tip of the tubes. The revolving head, trunnion rings and trunnion cups, including the cushion, shall be soundly constructed to withstand the maximum centrifugal force capable of being delivered by the power source. The trunnion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if any breakage occurs. Calculate the speed of the rotating head as follows:

$$\text{rpm} = 265 \sqrt{\frac{\text{rcf}}{d}}$$

TABLE I.—PEAR-SHAPED CENTRIFUGE TUBE CALIBRATION TOLERANCES.

Range, ml	Smallest Scale Division, ml	Maximum Scale Error, ml
0 to 1.5	0.1	0.03
Over 1.5 to 3.0	0.5	0.20
Over 3.0 to 5.0	0.5	0.30
Over 5.0 to 10.0	1	0.50
Over 10 to 25	5	1.0
Over 25 to 100	25	2.0

TABLE II.—CONE-SHAPED CENTRIFUGE TUBE, CALIBRATION TOLERANCES.

Range, ml	Smallest Scale Division, ml	Maximum Scale Error, ml
0 to 0.1	0.05	0.02
Over 0.1 to 0.3	0.05	0.03
Over 0.3 to 0.5	0.05	0.05
Over 0.5 to 1.0	0.1	0.05
Over 1.0 to 2.0	0.1	0.10
Over 2.0 to 3.0	0.2	0.10
Over 3.0 to 5.0	0.5	0.20
Over 5.0 to 10.0	1	0.50
Over 10 to 25	5	1.0
Over 25 to 100	25	1.0

where:

rcf = relative centrifugal force, and
d = diameter of swing, inches, measured between tips of opposite tubes when in rotating position."

Section 2 (b).—Change to read as follows: "(*b*) *Centrifuge Tube*, pear-shaped or cone-shaped, conforming to dimensions given in Figs. 1 and 2, respectively, and made of thoroughly-annealed glass. The graduation, numbered as shown in Figs. 1 and 2, shall be clear and distinct, and the mouth constricted in shape for closure with a cork. Scale error tolerances and smallest graduations between various calibration marks are given in Tables I and II, and apply to calibrations made with air-free water at 20 C."

Fig. 1.—Same as present Fig. 1.
Fig. 2.—Revise as shown in accompanying Fig. 2.

Section 4 (b).—Change the first sentence to read as follows: "The two centrifuge tubes or pairs of tubes shall then be shaken vigorously for 10 sec, placed in their respective trunnion cups and balanced against each other. They shall then be placed on opposite sides of the head and whirled for 10 min at a rate, calculated from the equation in Section 2 (*a*), sufficient to produce a relative centrifugal force (rcf) of between 500 and 700 at the tips of the whirling tubes (see Table III for relationship between diameter swing, rcf, and rpm)."

D 130 - 50 T.[11] Test for Free and Corrosive Sulfur in Petroleum Products:

Appendix.[12a]—Add, as information only, an appendix to read as follows: "The following proposed revision of Sections 3 (*a*) and 6 (*b*), and Fig. 1, is under consideration by Committee D-2 on Petroleum Products and Lubricants, and is published here as information only:

TABLE III.—ROTATION SPEEDS APPLICABLE FOR CENTRIFUGES OF VARIOUS DIAMETERS.

Diameter of Swing, in.[a]	Rpm at 500 rcf	Rpm at 700 rcf
12	1710	2030
13	1650	1950
14	1590	1880
15	1530	1810
16	1480	1760
17	1440	1700
18	1400	1660
19	1360	1610
20	1330	1570
21	1300	1530
22	1270	1500
23	1240	1460
24	1210	1430

[a] Measured in inches between tips of opposite tubes when in rotating position.

"*Sample Bomb* conforming to the design shown in Fig. 5 (the accompanying Fig. 3). Provide a 25 by 150-mm test tube as a liner for holding the sample."

"*Test at 212 F for Aircraft Engine Fuels.*—Place 30 ml of carefully dried sample (Note 2) in a chemically clean, dry 25 by 150-mm test tube and, within 1 min after completing the final polishing, slide the copper strip into the sample tube. Carefully slide the test tube with sample into the sample bomb (Fig. 1) and screw the lid on tight. Completely immerse the bomb in a boiling water bath (212 ± 1 F). After 1 hr ± 5 min in the bath, withdraw the bomb, immerse for a few minutes in tap water; open, withdraw the test tube, and examine the strip as described in Paragraph (*c*)."

D 270 - 50 T.[11] Sampling Petroleum and Petroleum Products. The proposed revisions to this method are extensive and are appended hereto.[13]

D 445 - 46 T.[3] Test for Kinematic Viscosity:

Replace the present text of the method with the text of the Proposed Method of Test for Kinematic Viscosity which appeared as Appendix V, 1951 Report of Committee D-2,[14] deleting Section 5 (*c*).

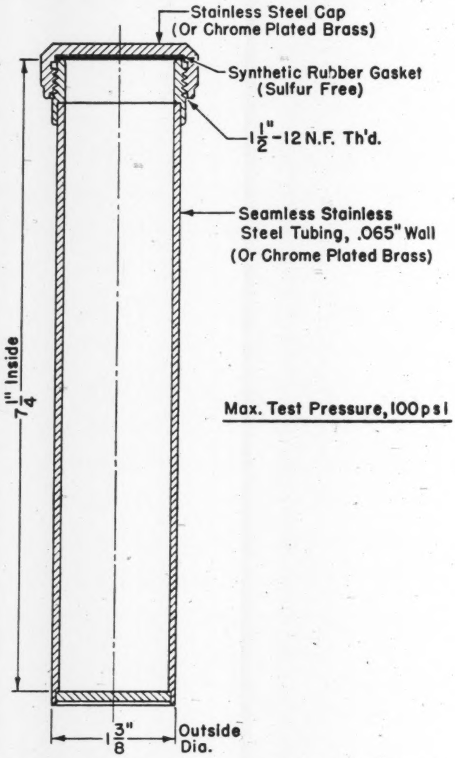

FIG. 3.—Copper Strip Corrosion Test Bomb.

D 447 - 51 T.[12] Test for Distillation of Plant Spray Oils, revise as follows:

Appendix.—In Section A-2 change the first sentence to read: "A condenser 9/16 in. in outside diameter with 0.031 in. to 0.036 in. wall thickness, made of seamless brass tubing, 22 in. in length."

[12a] Accepted for publication as information as an Editorial Note appended to Method D 130.

[13] The revised method was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 5.

[14] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 320 (1951).

D 483 – 51 T.[12] Test for Unsulfonated Residue of Petroleum Plant Spray Oils, revise as follows:

Section 3 (a).—Add the following note and renumber subsequent notes:

"NOTE 1.—The buret should be subdivided to 0.01 ml or 0.02 ml and be provided with a tip delivering drops of approximately 0.01 ml. Corrections to the nominal values of the buret should be obtained in the laboratory and used in the calculation."

Section 3 (e).—Revise to read as follows: "(*e*) *Centrifuge.*—Capable of whirling two or more filled sulfonation flasks at a speed which can be controlled to give a relative centrifugal force (rcf) of between 80 and 100 at the bottom of the flasks (see Note 2). The revolving head, trunnion rings, and trunnion cups including the cushion, shall be soundly constructed to withstand the maximum centrifugal force capable of being delivered by the power source. The trunnion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if breakage occurs. Calculate the speed of the rotating head by means of the following equation:

TABLE IV.—ROTATION SPEEDS FOR CENTRIFUGES OF VARIOUS DIAMETERS OF SWING.

Diameter of Swing, in.[a]	Rpm at 80 rcf	Rpm at 100 rcf
20	530	590
21	520	580
22	510	570
23	500	550
24	490	540

[a] Measured in inches between bottoms of opposite flasks when in rotating position.

$$\text{rpm} = 265\sqrt{\frac{\text{rcf}}{d}}$$

where:

rcf = relative centrifugal force, and

d = diameter of swing, inches, measured between bottoms of opposite flasks when in rotating position.

"NOTE 2.—The centrifuge usually specified for the rcf range of 500 to 700 is adaptable for this lower speed. Since separation is accomplished at the lower speed, it is considered inadvisable to increase speed and corresponding breakage hazard."

Section 4 (b).—Revise to read: "(*b*) *Sulfuric Acid.* (sp. gr. 1.84, approximately 95 per cent).

Section 5 (e).—Revise to read as follows:

"(*e*) After the final shaking, cool to approximately room temperature, and add sufficient concentrated sulfuric acid (95 per cent) to raise the oil into the neck of the flask nearly to the top graduation. Place the flasks and holders on the opposite sides of the centrifuge head and centrifuge for 10 min at a speed calculated by the equation in Section 3 (*e*) or taken from the accompanying Table IV to give a relative centrifugal force between 80 and 100 at the bottom of the flask. Transfer the flasks to a water bath maintained at 77 ± 1 F for 10 min, with the graduated neck immersed to the upper oil level.

NOTE 7.—The use of rubber cushions in the centrifuge carrier tubes to avoid breakage is recommended."

Appendix.—Change first sentence of Section A1. (*b*), to read: "(*b*) Sulfonation Flask, glass-stoppered,[3] as shown in Fig. 2, may be used (without the glass stopper) instead of . . . .etc."

D 524 – 51 T.[12] Test for Carbon Residue of Petroleum Products (Ramsbottom Coking Method), revise as follows:

Section 8.—Change to read as follows:

"*Precision.*—The criteria below should be used for judging the acceptability of the results when testing homogeneous samples. Carbon residue values of less than 0.1 per cent are not reliable, as shown by the curves in Figs. 4 and 5.

"(*a*) *Repeatability.*—Duplicate results by the same operator should not differ by more than the corresponding percentage as shown in Fig. 4 for repeatability *versus* average per cent residue.

"(*b*) *Reproducibility.*—The average of two results obtained in each of two laboratories should not differ by more than the corresponding percentage as shown in Fig. 5 for reproducibility *versus* average per cent residue.

New Figures 4 and 5.—Add new Figs. 4 and 5 and renumber subsequent figures accordingly.

Appendix.—Add a new Section A3 to read as follows:

"*A3. Information Concerning Correlation of Carbon Residue Results Determined by the Two Methods, D 524 – 52 T and D 189 – 52.*—An exact relationship between the Ramsbottom carbon residue as determined by this Tentative Method D 524, and the Conradson carbon residue as determined by the Standard Method D 189, does not exist because of the poor precision of both methods of test on samples with low percentages of carbon residue. An empirical correlation (Fig. 7)[15] has been developed as a guide to the correlation or conversion of results. This correlation was determined by plotting results obtained by both methods of test on a number of representative petroleum products. There was some scattering of the points; therefore, the curve shown in Fig. 7 represents the average relationship between carbon residues as determined by the two methods over a range of 0.01 per cent to 10 per cent by the Conradson Method D 189 - 52. That portion of the curve below 0.1 per cent Conradson carbon residue is shown as a dotted line. This is in accordance with the statement in Section 5 of Method D 189 - 52 and Section 8 of Method D 524 - 52 that carbon residue values of less than 0.1 per cent are not reliable. The correlation shown in Fig. 7 makes no allowance for the combined permissible deviations from the average as specified in the two methods. It is possible that carbon residue test results by both methods on unusual types of petroleum products would not fall near the same correlation line."

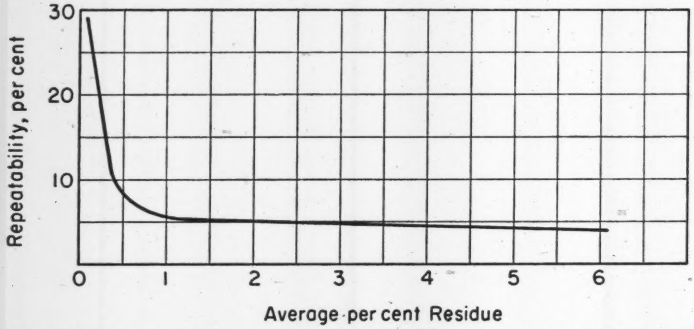

FIG. 4.—Repeatability *versus* Average Per Cent Residue, Ramsbottom Carbon Residue.

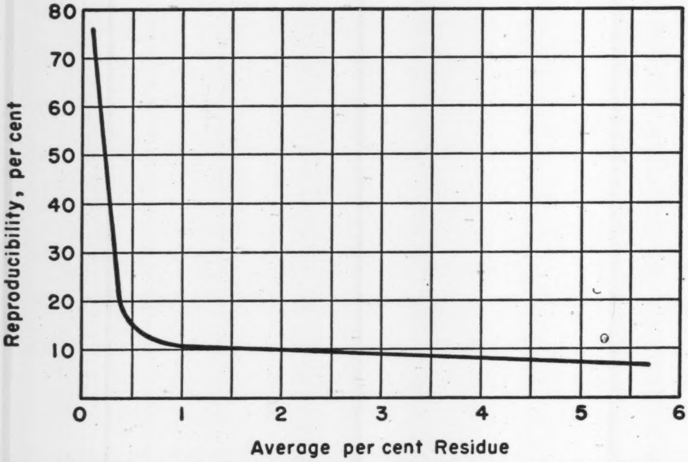

FIG. 5.—Reproducibility *versus* Average Per Cent Residue, Ramsbottom Carbon Residue.

D 665 - 50 T.[11] Test for Rust-Preventing Characteristics of Steam-Turbine Oil in the Presence of Water, revise as follows:

Section 4(a).—Change last two sentences to read:

"It shall be made of steel conforming to grade 1015, 1020, or 1025 of the Tentative Specifications for Cold-Finished Carbon-Steel Bars and Shafting (ASTM Designation: A 108). If these steels are not available, other equivalent steels may be used, provided they are found to be satisfactory by comparative test using Method D 665. The steel specimen, either new or from a previous."

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[15] This Fig. 7 is the same as Fig. 4 of D 189 (Fig. 9 in this report; see p. 339).

D 808 - 51 T.[12] Test for Chlorine in Lubricating Oils and Greases by the Bomb Method, revise as follows:

Preamble.—Add a Preamble in bold face type in the heading of the method to read: "Attention is called to the paragraph on Safety and to the specific precautionary directions incorporated in the method.

Section 2a.—Add a Paragraph 2(*b*), in italics, to read as follows:

"*2.* (*b*) **Safety.**—*Strict adherence to all of the provisions prescribed hereafter insures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least* $\frac{1}{2}$ *in. thick, or equivalent protection be provided against unforeseeable contingencies.*"

Section 3 (*d*).—Add the following paragraph in italics:

"*3.* (*d*) **Caution.**—*The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.*"

Section 5 (*a*).—Add the following paragraph in italics just preceding the table: "5. (*a*) **Caution.** *Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.*"

Note 2. Revise Note 2 to read as follows: "NOTE 2.—If the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil."

Section 5 (*b*).—Add the following sentence in italics after the second sentence:

"*5.* (*b*) **Caution.**—*Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.*"

Also in Section 5 (*b*) revise the table to read as follows:

Capacity of Bomb, ml	Minimum Gage Pressure, atmospheres	Maximum Gage Pressure, atmospheres
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

Add the following after the table: "The minimum pressures are specified to provide sufficient oxygen for complete combustion, and the *maximum pressures represent a safety requirement.*"

Section 5 (*c*).—Delete the first sentence and replace with the following: "Immerse the bomb in a cold distilled-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample."

Add the following phrase to the last sentence of Section 5 (*c*): "and thoroughly clean the bomb before again putting it in use (Note 1)."

D 855 - 46 T.[3] Methods of Analysis of Petroleum Sulfonates. The method has been extensively revised and is appended hereto.[13]

D 893 - 50 T.[3] Test for Normal Pentane and Benzene Insolubles in Used Lubricating Oils, revise as follows:

Section 4.—Change to read as follows:

"4. *Apparatus.*—The apparatus shall consist of the following:

(*a*) *Centrifuge Tube,* cone-shaped, conforming to dimensions given in Fig. 1, and made of thoroughly-annealed glass. The graduations, numbered as shown in Fig. 1 (the accompanying Fig. 2), shall be clear and distinct and the mouth constricted in shape for closure with a cork. Scale error tolerances and smallest graduations between various calibration marks are given in Table I and apply to calibrations made with air-free water at 20 C."

Table I.—Add new Table I to read the same as Table II given above under revision of Method D 96.

(*b*) *Centrifuge,* capable of whirling two or more filled centrifuge tubes at a speed which can be controlled to give a relative centrifugal force (rcf) between 600 and 700 at the tip of the tubes. The revolving head, trunnion rings, and trunnion cups, including the rubber cushion, shall be soundly constructed to withstand the maximum centrifugal force capable of being delivered by the power source. The trunnion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if any breakage occurs. Calculate the speed of the rotating head by means of the following equation:

$$\text{rpm} = 265 \sqrt{\frac{\text{rcf}}{d}}$$

where:

rcf = relative centrifugal force, and

d = diameter of swing, inches, measured between tips of opposite tubes when in rotating position."

Section 7 (b).—Revise to read as follows: "(*b*) Remove the stopper, and by means of a wash bottle having a fine jet, wash all insolubles from the stopper into the centrifuge tube with a minimum of *n*-petane. Balance each pair of filled centrifuge tubes, place them in the centrifuge on opposite sides of the head, and centrifuge for 20 min at a rate, calculated from the equation in Section 4(*b*), sufficient to produce a relative centrifugal force (rcf) between 600 and 700 at the tips of the whirling tubes. (Table II, shows the relationship between diameter swing, rcf, and rpm.)"

TABLE V.—ROTATION SPEEDS FOR CENTRIFUGES OF VARIOUS DIAMETERS.

Diameter of Swing, in.[a]	Rpm at 600 rcf	Rpm at 700 rcf
19	1490	1610
20	1450	1570
21	1420	1530
22	1390	1500

[a] Measured in inches between tips of opposite tubes when in rotating position.

Table II.—Add new Table II to read the same as the accompanying Table V.

Delete present footnote 3.

D 974 - 51 T.[3] Test for Neutralization Value (Acid and Base Numbers) by Color-Indicator Titration, revise as follows:

"NOTE 3.—Delete the following phrase from the first sentence "insolubility in the titration solvent or."

D 975 - 51 T.[12] Classification of Diesel Fuel Oils, revise as follows:

Footnote "d".—Delete this footnote.

Appendix.—Reletter as "Appendix I."

New Appendix B.—Add a new Appendix II which will contain a method for estimating ASTM cetane numbers, similar to the Method for Determining Calculated Cetane Index[16] published in the 1951 Supplement to the ASTM Manual of Engine Test Methods for Rating Fuels, and will be included "as information only," with editorial changes.

D 1016 - 51 T.[12] Test for Determination of Purity from Freezing Points, revise as follows:

Section 12 (d).—Change freezing point of 2,2,4-trimethylpentane, to read as follows: "$t_{fo} = -107.380 \pm 0.010$ C"

D 1085 - 50 T.[11] Method of Gaging Petroleum and Petroleum Products. The revisions to this method are so extensive that they are appended hereto.[13]

D 1086 - 50 T.[11] Method of Measuring the Temperature of Petroleum and Petroleum Products, revise as follows:

Fig. 1.—Change the width of cup at the bottom of the cup case assembly from "2 in. approx." to read "1¾ to 2 in." so as to permit use of this type case in a 2-in. gage pipe.

Table II.—Add the following new item:

Name	Range	Graduation	Accuracy
Mercury-Actuated, Dial	Suitable Range	1 F	±1.0 F

Section 4.—Add a new Paragraph (*g*) to read as follows:

(*g*) *Mercury-Actuated, Dial.*—A mercury-actuated thermometer with dial indicator is installed in a tank, similar to the installation shown in Fig. 4. The stem of the thermometer shall be at least 3 ft long and the sensitive portion not more than 2.5 in. long. The assembly is attached to the well by a threaded coupling."

Add a new Paragraph (*h*) to read as follows:

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[16] See 1951 Supplement to ASTM Manual of Engine Test Methods for Rating Fuels.

"(*h*) *Electrical Resistance Thermometers.*—Electrical resistance thermometers are sometimes used to determine both *average* and *spot* temperatures of oils in storage tanks; and, therefore, the following information is included herein for information only. The instruments are based on the principle that certain metals, such as copper, nickel, silver, and platinum, have the property of changing their electrical resistance uniformly with changes in temperature. The averaging type of assembly consists of a bundle of helically-wound metal resistors (of various lengths but of equal resistance), inserted in a pipe or flexible cable and suspended vertically in the tank. These resistors are connected, by means of a selector switch, to a meter assembly which consists of a wheatstone bridge circuit, a voltage supply, and a meter calibrated in temperature units, degrees F. The selector switch is used to connect the longest completely-submerged resistor to the meter; and the *average* temperature of the oil is indicated on the dial. The meter may be located on the tank top, at ground level, or at any remote point. A ratio-type meter or its equivalent should be used to compensate for voltage variations in the power supply to prevent erroneous readings. The scale can be of any suitable range, although a scale spread of more than 120 deg should be avoided if a sustained accuracy of ± 0.5 F is desired. The circuit for a *spot* type of assembly is the same as that described above, except that one or more short tubular-type resistors are generally used in place of the bundle of averaging-type resistors. These resistors are placed at specific locations in the oil body (wherever spot temperatures are desired) and connected to the meter assembly by means of a selector switch. The temperature at the location of any resistor can be obtained by manipulating the switch.

It is believed that this type thermometer may gain wide acceptance, especially when used in conjunction with remote reading mechanical gaging devices."

Section 8 (*c*).—Revise the third sentence to read: "If the atmospheric temperature differs by more than 20 F from that of the product in the tank, the cup case assembly shall be given two or more preliminary immersions, emptying the cup after each immersion. This will assist the assembly to approach temperature equilibrium before the final immersion and reduce required immersion time."

Table III.—Add the following note to Table III:

"NOTE.—For crude oil tanks over 10 ft in height, having a capacity of less than 5000 bbl, one temperature measurement at the middle of the oil may be used."

Table IV.—Revise Table IV as follows:

Product	Minimum Immersion Time, min.
Crude, gasoline, naphtha, kerosine, gas oil and other oils of Saybolt Universal Viscosity less than 100 sec at 100 F. . . .	5
Crude, light lubricating, fuel, and other oils of Saybolt Universal Viscosity above 100 sec at 100 F and below 170 sec at 210 F. . . .	15
Crude, heavy lubricating, cylinder, gear, residual, and other oils of Saybolt Universal Viscosity above 170 sec at 210 F.	30

D 1087 – 50 T.[11] Volume Calculations and Corrections in the Measurement of Petroleum and Petroleum Products, revise as follows:

Section 4 (*c*).—Change the second sentence to read: "Obtain this factor from Table 7, ASTM-IP Petroleum Measurement Tables (American Edition)."

Section 5.—Revise to read as follows:

"5. (*a*) *Floating Roof.*—Under normal operating conditions, the roof is in a floating position for both opening and closing gages. Therefore, corrections for the weight of product displaced by the roof need not be made, because it is the same for both opening and closing gages. If the roof is in a partially floating position, the measured quantity cannot be calculated accurately. Although it is not good operating practice for safety or loss control, it is sometimes necessary to draw the product away from the roof completely so that the roof rests on its supports. Where this condition occurs for either the opening or closing gage, calculate the delivered or received quantity at 60 F by the following procedure. Use the following formula to calculate the quantity equivalent to the roof displacement:

$$Q = WG \quad \text{or} \quad Q = \frac{W}{P}$$

where:

Q = gallons equivalent to the roof displacement,
W = weight of the floating roof in pounds,
G = gallons per pound of product, and
P = pounds per gallon of product.

The weight of the roof is stamped on the roof manhole plate and printed on the capacity table. Obtain the pounds per gallon or gallons per pound of the product from Table 3 of the ASTM-IP Petroleum Measurement Tables (American Edition)."

"(*b*) *Example.*—The following illustrates the recommended procedure for calculating the quantity of product at 60 F, for the case when the floating roof is resting upon its supports at the opening gage:

Roof resting on supports at opening gage:

W, weight of floating roof (from capacity table, lb)	126,897
API Gravity at 60 F of product (32.5 at 80 F)	31.1
API Indicated Gravity of product (at tank temp)	32.5
P, pounds per gallon of product (from Table 3)	7.184
Q, roof displacement (126,897 + 7.184), gal.	17,664

Quantity at 60 F:	*Opening Gage*	*Closing Gage*
Measured gallons	103,624	715,771
Q, correction for roof displacement	None	17,664
Corrected measured gallons	103,624	698,107
Temp. of tank contents, F	81	80
Volume correction factor (from Table 7)	0.9917	0.9921
Net gallons at 60 F	102,764	692,592
Received at 60 F (by subtraction), gal.	....	598,828

Section 6.—Revise to read as follows:

"6. (*a*) *Roof as Deadwood.*—Do not correct for the condition outlined in Section 5 (*a*) if a quantity equivalent to the roof displacement has been subtracted from the capacity table as "deadwood." However, since the roof displacement is calculated for a product of a definite API gravity, corrections must be made for products having different API gravities. Obtain measured quantity directly from the capacity table, and apply the correction noted on the capacity table for the difference in API gravity. The total correction is the difference between the volumes displaced by the roof at the API gravity of the product and at the API gravity for which the "deadwood" deduction on the capacity table was made. The correction is added for a product of lower API gravity and substracted for one of higher gravity.

"(*b*) *Example.*—The following illustrates the recommended procedure for calculating the net quantity of product at 60 F, for the case when the capacity table has been corrected for the roof displacement:

Note on the Capacity Table:

"A total of 635.68 bbl has been deducted from this table between 2 ft 3 in. and 3 ft 6 in. for roof displacement based on a weight of 176,210 lb and a gravity of 47° API with roof in its lower position. For any gage above 3 ft 6 in., apply corrections for varying API observed gravities (indication at tank temperature) as follows:

At 47° API	No Correction
Each degree below 47° API	Add 3.56 bbl.
Each degree above 47° API	Subtract 3.56 bbl.

Calculations:	*Opening Gage*	*Closing Gage*
Innage gage	27 ft. 2 in.	2 ft. 1⅓ in.
Water innage	0 ft. 2 in.	0 ft. 2⅛ in.
Temperature, F	81	80
API Gravity at 60 F.	48.7	48.6
Observed Gravity at Tank Temp.	50.7	50.5
Volume correction factor	0.9896	0.9901
Measured quantity	51,043.00	3,730.26
Measured quantity	51,043.00	3,730.26
Gravity variation from 47.0° API	3.7	3.5
Correction (3.7 × 3.56), bbl	13.17	None (roof at rest)
Corrected measured quantity	51,029.83	3,730.26
Volume correction factor	0.9896	0.9901
Quantity at 60 F	50,499.12 3,693.33	3,693.33
Delivered net quantity at 60 F	46,805.79 bbl.	

NOTE.—For referee measurements:

(To compute gravity change to be used with above-mentioned table)—

(*a*) Use average gravity and average temperature of material in tank.

(*b*) Use gravity and temperature of material immediately under roof, where abnormal conditions of stratification exist, and it is impractical to reblend contents of tank.

(Means shall be provided for the determination of stratification)."

Section 10 (*a*).—Revise the second sentence from "Freight Tariff No. 4 containing Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles by Freight (or the latest supplement thereto or reissue thereof) as issued by H. A. Campbell, Agent," to read as follows: "Tariff No. 8, containing ICC Regulations for Transportation of Explosives and Other Dangerous Articles by Land and Water in Rail Freight Service and by Motor Vehicle (Highway) and Water (or the latest supplement thereto or reissue thereof) as issued by H. A. Campbell, Agent."

Section 10 (*b*).—Revise the second line to read: "Summer filling density (from Tariff No. 8), per cent 55.5."

Change the third line to read: "Volume correction factor (Table 25 ASTM-IP Petroleum Measurement Tables (American Edition))."

D 1158 – 51 T.[12] Test for Bromine Number of Petroleum Distillates (Color-Indicator Method).

Appendix.—Include in an appendix the "Reported Behavior of Compounds in the Color Indicator and Electrometric Bromine Number Methods,"[17] and revise Table II of this proposed Appendix to read as shown in the accompanying Table VI.

D 1159 – 51 T.[12] Test for Bromine Number of Petroleum Distillates (Electrometric Method). The method has been revised by the addition of the following reference at the end of the method: "For reported behavior of compounds in the Color-Indicator and Electrometric Bromine Number Methods, see the appendix to Method D 1158."

TABLE VI.—REPORTED BEHAVIOR OF HYDROCARBON COMPOUNDS BY THE COLOR INDICATOR AND ELECTROMETRIC BROMINE NUMBER METHODS.

Compound	Purity per cent	Bromine Number				
		Theory	Color Indicator Method		Electrometric Method	
			Found	Deviation	Found	Deviation
STRAIGHT-CHAIN OLEFINS						
1-Dodecene	(Now in Table)					
1-Tetradecene	99.7	81.4	81.1	−0.3	82.4	+1.0
1-Hexadecene	97	71.2	71.0	−0.2	71.9	+0.7
1-Octadecene	(Now in Table)					
BRANCHED-CHAIN OLEFINS						
4-Methyl-1-Pentene	(Now in Table)					
4-Methyl cis-2-Pentene	99.7	189.9	187.5	−2.4	193.5	+3.6
4-Methyl trans-2-Pentene	99.4	189.9	189.1	−0.8	191.8	+1.9
2,3 Dimethyl-1-Butene	99.8	189.9	222.3	+32.4	217.7	+27.8
2,3 Dimethyl-2-Butene	99.7	189.9	194.9	+5.0	192.8	+2.9
2-Ethyl-1-Butene	(Now in Table)					
4,4 Dimethyl-2-Pentene	(Now in Table)					
2,3,3 Trimethyl-1-Butene	98.6	162.8	194.4	+31.6	192.0	+29.2
2-Ethyl-1-Hexene	(Now in Table)					

D 1160 – 51 T.[12] Test for Reduced Pressure Distillation of Petroleum Products. The method has been extensively revised and is appended hereto.[13]

TENTATIVE REVISION OF STANDARDS

Committee D-2 recommends publication of the tentative revision, in the form of a new tentative as appended hereto,[4] of the Standard Method D 381 – 50,[11] Test for Existent Gum in Gasoline (Air-Jet Evaporation Method).

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee D-2 recommends that the following standard be revised as indicated and reverted to tentative:

D 217 – 48.[3] Method of Test for Cone Penetration of Lubricating Grease, revise as follows:

Appendix A1. Cone.—Delete the second sentence and replace with: "The total weight of the cone shall be 102.5 ± 0.05 g and that of its movable attachments shall be 47.5 ± 0.05 g."

Figure 4.—Replace with the new Fig. 4 (the accompanying Fig. 6). Add a new paragraph A4 to the Appendix. This new paragraph will be the Test for Penetration of Lubricating Greases Worked More Than 60 Strokes (see Appendix I, 1951 Report of Committee D-2).[18]

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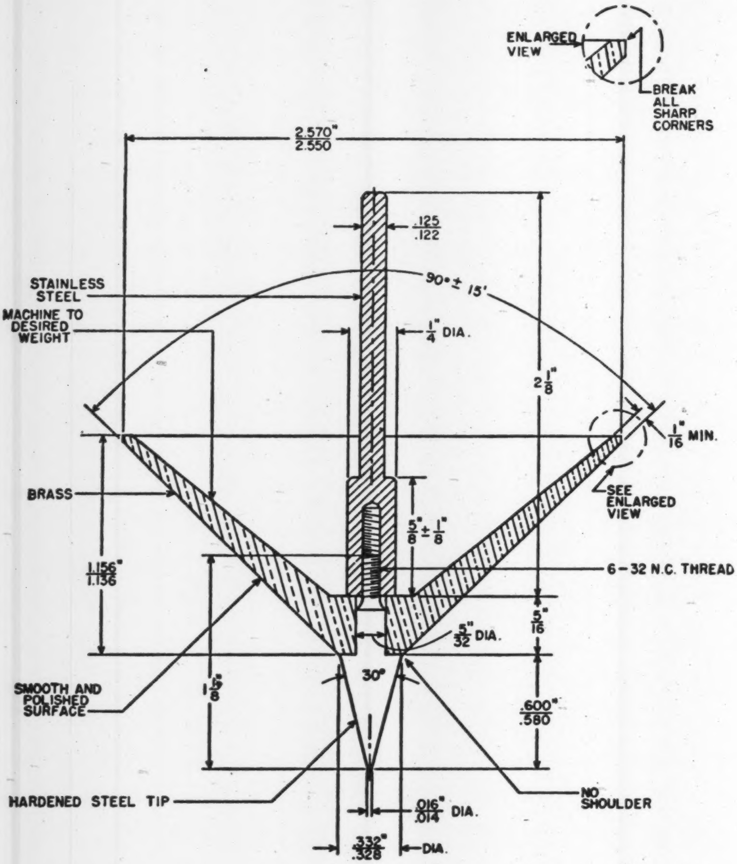
[17] Compilation of "ASTM Standards on Petroleum Products and Lubricants," September, 1951, p. 695.

[18] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 302 (1951).


ENLARGED VIEW
BREAK ALL SHARP CORNERS
2.570"/2.550
.125/.122
STAINLESS STEEL
90° ± 15'
MACHINE TO DESIRED WEIGHT
1/4" DIA.
2 1/8"
1/16" MIN.
SEE ENLARGED VIEW
BRASS
5/8" ± 1/8"
6-32 N.C. THREAD
1.156"/1.136
5/16"
5/32" DIA.
30°
SMOOTH AND POLISHED SURFACE
1 5/8"
.600"/.580
HARDENED STEEL TIP
NO SHOULDER
.016"/.014 DIA.
.332"/.328 DIA.

ALL FRACTIONAL DIMENSIONS $\pm\frac{1}{64}$"

Note.—Total weight of the cone shall be 102.5 ± .05g. and of its movable attachments shall be 47.5 ± .05g.

FIG. 6.—Penetrometer Cone.

ADOPTION OF TENTATIVES AS STANDARD

Committee D-2 finds that the following tentatives represent the best present-day practices, in each case, and recommends that they be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Methods of:

D 1020 - 49 T. Test for Acetylene in Polymerization Grade Butadiene by Silver Nitrate Method

D 1023 - 49 T. Test for Separation of Residue from Butadiene,

D 1025 - 49 T. Test for Nonvolatile Residue of Polymerization Grade Butadiene, and

D 1093 - 50 T. Test for Acidity of Residue from Distillation of Gasoline and Petroleum Solvents.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Committee D-2 recommends for immediate adoption revisions as indicated in the following standards, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

D 484 – 40.[3] Specifications for Stoddard Solvent, revise as follows:

Section 4 (*d*).—Delete present paragraph on "Apparatus." Replace with:

"(*d*) ***Sulfuric Acid Absorption Test: Apparatus.*** —Sulfonation flask meeting the requirements shown in Fig. 1 and pipet standardized to agree with the flask.

Centrifuge (not required but permitted), capable of whirling two or more sulfonation flasks at a controlled speed sufficient to give a relative centrifugal force between 80 and 100 at the bottom of the flasks.

$$\text{rpm} = 265\sqrt{\frac{\text{rcf}}{d}}$$

where:

rcf = relative centrifugal force, and

d = diameter of swing, inches, measured between bottoms of opposite flasks when in rotating position.

"Note 1.—The standard two-cup, hand-driven, milk-test centrifuge for 6-in. Babcock bottles may be used. The penny heads of the stoppers must be aligned in the same vertical plane to prevent breakage."

Add a paragraph preceding "Procedure," to read: "*Reagent.*—Sulfonation acid prepared by making a dilution of concentrated sulfuric acid (sp gr 1.84) to give a concentration of 93.2 ± 0.3 per cent, determined by titration."

Revise the paragraph on "Procedure" as follows:

Change the third sentence to read: "Add from a graduate 20 ml of H_2SO_4 (93.2 ± 0.3 per cent) previously cooled in ice water for 5 min."

Starting with the seventh sentence, revise to read: "Carefully add to the bottle sufficient sulfuric acid to bring the liquid level almost to the top graduation. Centrifuge at a speed to give a relative centrifugal force between 80 and 100 at the bottom of the flask or, alternatively, allow the stoppered bottle to stand overnight (at least 12 hr). Place the bottle in a water bath at 20 ± 1 C . . . .etc."

D 56 – 51.[12] Test for Flash Point by Tag Closed Tester, revise as follows:

Section 3 (*c*).—Add a note to read as follows:

"Note.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 15 F (or 15 C) P.M.-Low' or 'IP 16 F (or 16 C) P.M. High' may be used, provided calibration corrections are used in temperature ranges where IP requirements for scale accuracy are less stringent than those of ASTM."

D 86 – 46.[3] Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products, revise as follows:

Section 2 (*b*).—Change the first sentence to read: "A condenser (Fig. 2 shows one of the approved types) $\frac{9}{16}$ in. (14.29 mm) in outside diameter with 0.031 in. to 0.036 in. wall thickness, made of seamless brass tubing, 22 in. (55.88 cm) in length.

Figure 2.—Delete the portion of the caption referring to the condenser. Replace with: "$\frac{9}{16}$-in. Outside Diameter × 0.031 to 0.036-in. Wall, Seamless Brass Tubing."

Section 2 (*h*).—Add a note to read as follows:

"Note.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements applicable to IP thermometers No. 5C (Low Distillation) and 6C (High Distillation) may be used, provided calibration corrections are used in temperature ranges where IP requirements for scale accuracy are less stringent than those of ASTM."

Section 3 (*a*).—Change last sentence to read: "The temperature shall be maintained at 32 to 34 F for gasolines higher than 9.5 Reid vapor pressure, and 32 to 40 F for other products."

Section 4 (*g*).—Replace the present paragraph with the following: "The sum of the recovery and the residue shall be calculated and recorded as *total recovery*."

Section 4 (*h*).—Add a new Paragraph, (*h*), to read as follows, and reletter subsequent paragraphs accordingly: "(*h*) The difference between 100 ml and the total recovery shall be recorded as *distillation loss*."

D 91 – 40.[3] Test for Precipitation Number of Lubricating Oils, revise as follows:

Section 3 (*a*) and (*b*).—Change to read the same as Section 4 (*a*) and (*b*) given above under revision of Method D 893.

Table I.—Add new Table I to read the same as Table II given above under revision of Method D 893.

Section 5 (*b*).—Revise the first three sentences to read as follows: "The two centrifuge tubes or pairs of tubes with their respective trunnion cups shall be balanced and placed on opposite sides of the centrifuge head. They shall be whirled for 10 min at a rate sufficient to produce a relative centrifugal force (rcf) between 600 and 700 at the tips of the whirling tubes (see Section 3(*b*)). (Table II, shows the relationship between diameter swing, rcf, and revolutions per minute.)"

Table II.—Add new Table II to read the same as Table V given above under revision of Method D 893, showing centrifuge speeds in revolutions per minute.

D 92 – 46.[3] Test for Flash and Fire Points by Means of Open Cup, revise as follows:

Section 2 (c).—Add the following note: "NOTE.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 28 F (or 28 C) Cleveland' may be used, provided calibration corrections are used in temperature ranges where the IP requirements for scale accuracy are less stringent than those of ASTM."

D 93 – 46.[3] Test for Flash Point by Means of the Pensky-Martens Closed Tester, revise as follows:

Section 2 (d).—Add the following note: "NOTE.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 15 F (or 15 C) P.M.-Low' or 'IP 16 F (or 16 C) P.M.-High' may be used, provided calibration corrections are used in temperature ranges where the IP requirements for scale accuracy are less stringent than those of ASTM."

D 129 – 51.[3] Test for Sulfur in Petroleum Products and Lubricants by the Bomb Method, revise as follows:

Preamble.—Add a Preamble to the heading of the method to read: "*Attention is called to the paragraph on Safety and to the specific precautionary directions incorporated in the method.*"

Section 2.—Reletter the first paragraph as 2 (*a*) and add a Paragraph (*b*) in italics to read as follows:

"(*b*) **Safety.**—*Strict adherence to all of the provisions prescribed hereafter insures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least $\frac{1}{2}$ in. thick, or equivalent protection be provided against unforeseeable contingencies.*"

Section 3 (d).—Add the following paragraph in italics:

"(*d*) **Caution.**—*The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.*"

Section 5 (a).—Add the following paragraph, in italics, just preceding the table:

"**Caution.**—*Do not use more than 1 g total of sample and white oil or other sulfur-free combustible material.*"

Note 2.—Change Note 2 to read: "NOTE 2.—If the sample is not readily miscible with white oil, some other nonvolatile, sulfur-free combustible diluent may be employed in place of the white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g."

Section 5 (b).—Add the following sentence in italics after the second sentence: "**Caution.**—*Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.*"

Also in Section 5 (*b*), revise the table to read as follows:

Capacity of Bomb, ml	Minimum Gage Pressure, atmospheres	Maximum Gage Pressure, atmospheres
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

After the Table add the following: "The minimum pressures are specified to provide sufficient oxygen for complete combustion and the *maximum pressures represent a safety requirement.*"

Section 5 (c).—Delete the first sentence and replace with the following: "Immerse the bomb in a cold distilled-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample."

To the last sentence of Section 5 (*c*), add the following phrase: "and thoroughly clean the bomb before again putting it in use (Note 1)."

D 158 – 41.[3] Test for Distillation of Gas Oil and Similar Distillate Fuel Oils, revise as follows:

Section 2 (b).—Change the first sentence to read: "A condenser $\frac{9}{16}$ in. (14.29 mm) in outside diameter, with 0.031 to 0.036 in. wall thick-

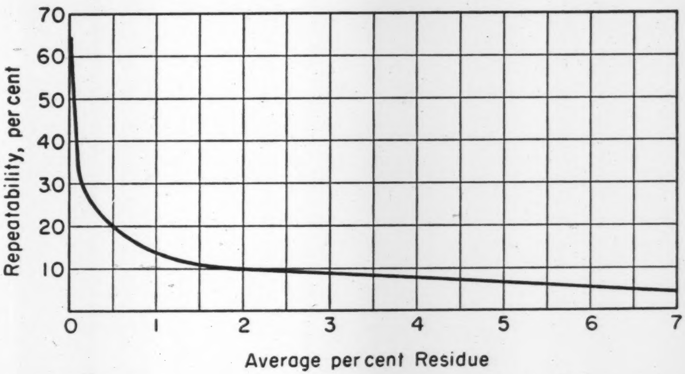


FIG. 7.—Repeatability *versus* Average Per Cent Residue, Conradson Carbon Residue.

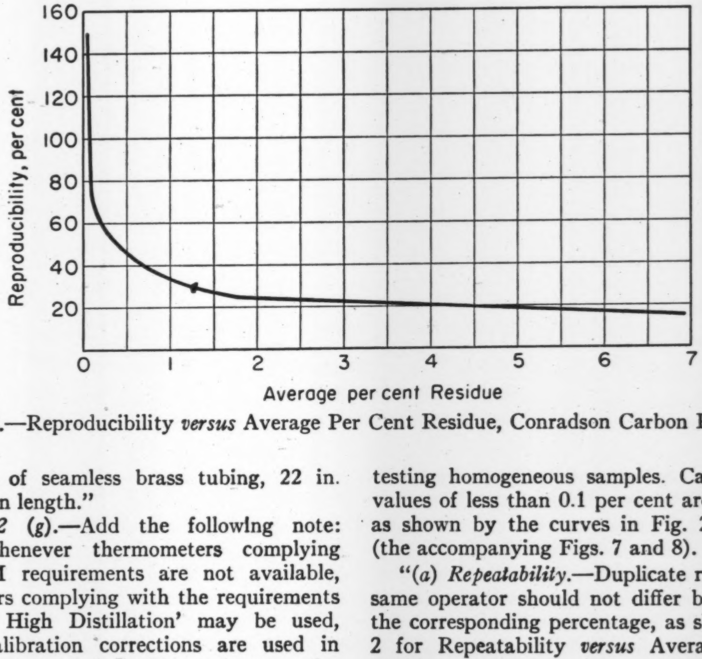


FIG. 8.—Reproducibility *versus* Average Per Cent Residue, Conradson Carbon Residue.

ness, made of seamless brass tubing, 22 in. (55.88 cm) in length."

Section 2 (g).—Add the following note: "NOTE.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 6C High Distillation' may be used, provided calibration corrections are used in temperature ranges where IP requirements for scale accuracy are less stringent than those of ASTM."

D 189 – 46.[3] Test for Carbon Residue of Petroleum Products (Conradson Carbon Residue), revise as follows:

Section 5.—Change the title of the section to read "Precision." Revise the section to read as follows:

"5. The criteria below should be used for judging the acceptability of the results when testing homogeneous samples. Carbon residue values of less than 0.1 per cent are not reliable as shown by the curves in Fig. 2 and Fig. 3 (the accompanying Figs. 7 and 8).

"(*a*) *Repeatability*.—Duplicate results by the same operator should not differ by more than the corresponding percentage, as shown in Fig. 2 for Repeatability *versus* Average per cent Residue.

"(*b*) *Reproducibility*.—The average of two results obtained in each of two laboratories should not differ by more than the corresponding percentage, as shown in Fig. 3 (the accompanying Fig. 8) for Reproducibility *versus* Average per cent Residue.

Appendix.—Delete the Appendix to the method and add a new Appendix to read as follows:

"*Information Concerning Correlation of Carbon Residue Results Determined by the Two Methods, D 189 – 52 and D 524 – 52 T*.—An exact relationship between the Conradson carbon residue as determined by this Standard Method D 189, and the Ramsbottom carbon residue as determined by the Tentative Method D 524, does not exist because of the poor precision of both methods of test on samples with low percentages of carbon residue. An empirical correlation (Fig. 4, the accompanying Fig. 9) has been developed as a guide to the correlation or conversion of results. This correlation was determined by plotting results obtained by both methods of test on a number of representative petroleum products. There was some scattering of the points; therefore, the curve shown in Fig. 4 (Fig. 9) represents the average relationship between carbon residues as determined by the two methods over a range of 0.01 per cent to 10 per cent by the Conradson Method D 189 – 52. That portion of the curve below 0.1 per cent Conradson carbon residue is shown as a dotted line. This is in accordance with the statement in Section 5 of D 189 – 52 and Section 8 of D 524 – 52 T that carbon residue values of less than 0.1 per cent are not reliable. The correlation shown in Fig. 4 (Fig. 9) makes no allowance for the combined permissible deviations from the average as specified in the two methods. It is possible that carbon residue test results by both methods on unusual types of petroleum products would not fall near the same correlation line."

Table I and Fig. 4.—Include in the new appendix "as information only" a new Table I (accompanying Table VII) and the curve in Fig. 4 (accompanying Fig. 9), showing the relationship between Ramsbottom and Conradson Carbon Residues.

D 216 – 40.[3] Test for Distillation of Natural Gasoline, revise as follows:

Section 2 (b).—Change first sentence to read: "A condenser (Fig. 2 shows one of the approved types) $\frac{9}{16}$ in. (14.29 mm) in outside diameter, with 0.031 to 0.036-in. wall thickness, made of seamless brass tubing, 22 in. (55.88 cm) in length."

Figure 2.—Delete the caption referring to the condenser and replace it with: "$\frac{9}{16}$-in. Outside Diameter × 0.031 to 0.036"-in. Wall, Seamless Brass Tubing."

Section 2 (g).—Add the following Note: "NOTE.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 5C Low Distillation' may be used, provided calibration corrections are used in temperature ranges where IP requirements for scale accuracy are less stringent than those of ASTM."

D 285 – 41.[3] Test for Distillation of Crude Petroleum, revise as follows:

Section 2 (c).—Change first sentence to read: "A condenser $\frac{9}{16}$ in. (14.29 mm) in outside diameter, with 0.031 to 0.036-in. wall thickness, made of seamless brass tubing, 22 in. (55.88 cm) in length."

TABLE VII.—AVERAGE RELATION BETWEEN RAMSBOTTOM AND CONRADSON CARBON RESIDUES, PER CENT.

R Ramsbottom	*C* Conradson	*F* Factor, $\frac{R}{C}$
0.06	0.01	6
0.08	0.02	4
0.10	0.04	2.5
0.20	0.15	1.3
0.30	0.27	1.1
0.40	0.40	1.0
0.50	0.52	0.96
0.60	0.65	0.92
0.70	0.79	0.89
0.80	0.92	0.87
0.90	1.06	0.85
1.00	1.20	0.83
1.10	1.34	0.82
1.20	1.49	0.81
1.30	1.60	0.81
1.40	1.75	0.80
1.50	1.90	0.79
1.60	2.03	0.79
1.70	2.19	0.78
1.80	2.30	0.78
1.90	2.45	0.78
2.00	2.60	0.77
2.50	3.30	0.76
3.00	3.95	0.76
3.50	4.60	0.76
4.00	5.27	0.76
4.50	5.95	0.76
5.00	6.50	0.77
6.00	7.80	0.77
7.00	8.95	0.78
8.00	10.00	0.80

Application of Correlation Factor (F) Column:

To calculate Conradson from Ramsbottom, $C = \frac{R}{F}$

To calculate Ramsbottom from Conradson, $R = C \times F$.

Section 2 (g).—Add the following note: "NOTE.—Whenever thermometers complying with ASTM requirements are not available, thermometers complying with the requirements for 'IP 5C Low Distillation' may be used, provided calibration corrections are used in temperature ranges where IP requirements for scale accuracy are less stringent than ASTM."

D 287 – 39.[3] Test for Gravity of Petroleum and Petroleum Products by

Means of the Hydrometer. The method has been extensively revised and is appended hereto.[13]

D 323 – 49.[3] Test for Vapor Pressure of Petroleum Products (Reid Method), revise as follows:

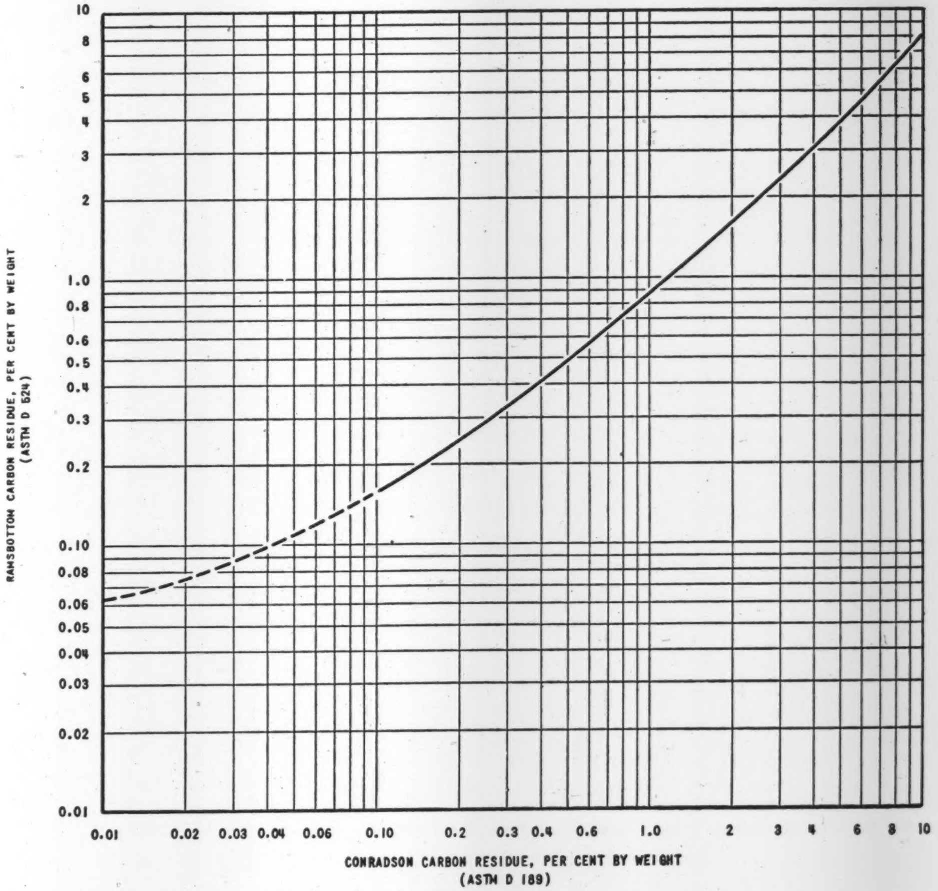


FIG. 9.—Relationship Between Ramsbottom and Conradson Carbon Residues.

Section 3 (b).—Revise as follows: In the table, change "12 and under" to read "3 to 12." Also in the table, add a new first line to read:

"4 and under.......... 0 to 5 1 0.1"

Add a Note 1 at the end of the section, to read: "NOTE 1.—Gages $3\frac{1}{2}$ in. in diameter may be used in the 0 to 5 lb range. Suitable gages may be obtained from Fisher Scientific Co. (Special Order) and U. S. Gage Co. (Catalogue No. 510 SP)." Renumber subsequent notes accordingly.

D 664 – 51.[12] Test for Neutralization Value (Acid and Base Numbers) by Electrometric Titration. The revisions to this method are so extensive that the revised method is appended hereto.[13]

D 939 – 50.[3] Test for Saponification Number of Petroleum Products by Potentiometric Titration, revise as follows:

Section 8 (*b*).—Delete the second sentence and replace with the following: "From a 50-ml buret, add 40 ± 0.05 ml of 0.2 *N* alcoholic KOH, allowing 60 to 80 sec to elapse between adding the first 39.5 ml and the final 0.5 ml."

Section 8 (*h*).—Delete the second sentence and replace with the following: "Without transfer of the saponification solution, cover the beaker with a watch glass, cool to room temperature, and titrate with 0.2 *N* alcoholic HCl directly in the saponification beaker within 2 hr after the end of the saponification period."

Standard Definitions of:

D 288 - 51.[12] Terms Relating to Petroleum, revise as follows:

Add the following statement to the beginning of the method: "In case of a dispute regarding the terms here defined, the definitions contained in this method are to be used in their entirety, all notes and supplementary comments being considered as part of the definition."

Delete the terms "Petroleum Grease" and "Petroleum Spirits (white spirits)" and include the following definitions:

"*Lubricating Grease.*—A solid to semi-fluid product of dispersion of a thickening agent in a liquid lubricant. Other ingredients imparting special properties may be included.

"*Kerosine.*—A refined petroleum distillate suitable for use as an illuminant when burned in a wick lamp.

"NOTE.—The flash point may not be below 73 F (23 C), as determined by the Abel Tester (which is approximately equivalent to 73 F (23 C) as determined by the Tag Closed Tester, ASTM Standard Method D 56). In the United States of America, local ordinances or insurance regulations require flash points higher than 73 F (23 C).

"*Petroleum Spirits* (*Mineral Spirits*).—A refined petroleum distillate with volatility, flash point, and other properties, making it suitable as a thinner and solvent in paints, varnishes, and similar products.

"NOTE 1.—Specifications are set forth in detail in the Standard Specifications for Petroleum Spirits (Mineral Spirits) (ASTM Designation: D 235).

"NOTE 2.—The term "Turpentine Substitute," as applied to petroleum spirits, is to be condemned as false and misleading. In Great Britain, the term 'petroleum spirits' is applied to a very light hydrocarbon mixture having a flash point below 32 F (0 C).

"*Precipitation Naphtha.*—A naphtha suitable for determination of the precipitation number of lubricating oils.

"NOTE.—Specifications are set forth in detail in ASTM Method D 91, Test for Precipitation Number of Lubrication Oils, and ASTM Method D 670, Test for Sludge Formation in Mineral Transformer Oil."

WITHDRAWAL OF TENTATIVES

Committee D-2 recommends the withdrawal of the following two tentatives:

D 809 - 50 T. Method of Chemical Analysis for Phosphorus in Lubricating Oils. The method is to be replaced by the more accurate Method D 1091 - 50 T, Test for Phosphorus in Lubricating Oils, Lubricating Oil Additives, and Their Concentrates.

D 1090 - 50 T. Factors and Tables for Volume Correction and Specific Gravity Conversion of Liquefied Petroleum Gases. The material in D 1090 is included in Tables 23 and 24 of the ASTM-IP Petroleum Measurement Tables (American Edition).

WITHDRAWAL OF STANDARDS

Committee D-2 recommends that the following two standards be withdrawn:

D 206 - 36. Abridged Volume Correction Table for Petroleum Oils, which is now superseded by Table 7 of the ASTM-IP Petroleum Measurement Tables (American Edition).

D 721 - 47. Test for Oil Content of Paraffin Wax. The method is to be replaced by Tentative Method D 721 - 51 T, Test for Oil Content of Paraffin Wax.

STANDARDS CONTINUED WITHOUT REVISION

Committee D-2 has reviewed the following fourteen standards, which have stood six or more years without revision and, because they are consistent with present-day practices, recommends their continuation without change:

Standard Methods of:

D 87 - 42. Test for Melting Point of Paraffin Wax,
D 88 - 44. Test for Viscosity by Means of the Saybolt Viscosimeter,
D 219 - 36. Test for Burning Quality of Long-Time Burning Oil for Railway Use,
D 239 - 30. Test for Burning Quality of Mineral Seal Oil,
D 286 - 30. Test for Autogenous Ignition Temperatures of Petroleum Products,
D 322 - 35. Test for Dilution of Crankcase Oils,
D 341 - 43. Viscosity-Temperature Charts for Liquid Petroleum Products,
D 446 - 39. Method for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity,
D 482 - 46. Test for Ash Content of Petroleum Oils,
D 565 - 45. Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum),
D 566 - 42. Test for Dropping Point of Lubricating Grease,
D 567 - 41. Method for Calculating Viscosity Index,
D 612 - 45. Test for Carbonizable Substances in Paraffin Wax, and
D 666 - 44. Method for Conversion of Kinematic Viscosity to Saybolt Furol Viscosity.

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-2 has reviewed the following twenty-two tentatives, which have stood for two or more years without revision and, for good and sufficient reasons, discussed within the committee, recommends their continuation without change:

Tentative Specifications for:

D 396 - 48 T. Fuel Oils.

Tentative Methods of:

D 90 - 50 T. Test for Sulfur in Petroleum Products by the Lamp-Gravimetric Method,
D 155 - 45 T. Test for Color of Lubricating Oil and Petrolatum by Means of ASTM Union Colorimeter,
D 526 - 48 T. Test for Tetraethyllead in Gasoline,
D 613 - 48 T. Test for Ignition Quality of Diesel Fuels by the Cetane Method,
D 614 - 49 T. Test for Knock Characteristics of Aviation Fuels by the Aviation Method,
D 875 - 46 T. Test for Olefins and Aromatics in Petroleum Distillates,
D 892 - 46 T. Test for Foaming Characteristics of Crankcase Oils,
D 909 - 49 T. Test for Knock Characteristics of Aviation Fuels by the Supercharge Method,
D 937 - 49 T. Test for Penetration of Petrolatum,
D 943 - 47 T. Test for Oxidation Characteristics of Inhibited Steam Turbine Oils,
D 976 - 48 T. Test for Color of U. S. Army Motor Fuel (All-Purpose) by Means of an ASTM Color Standard,
D 1015 - 49 T. Test for Measurement of Freezing Points for Evaluation of Purity,
D 1018 - 49 T. Test for Hydrogen in Petroleum Fractions by the Lamp Method,
D 1021 - 49 T. Test for Oxygen in Butadiene Vapors by Manganous Hydroxide Method,
D 1022 - 49 T. Test for Peroxides in Butadiene by Ferrous-Titanous Method,
D 1024 - 49 T. Test for Butadiene Dimer in Polymerization Grade Butadiene,
D 1089 - 50 T. Test for Carbonyl Content of Butadiene,
D 1091 - 50 T. Test for Phosphorus in Lubricating Oils, Lubricating Oil Additives, and Their Concentrates,
D 1094 - 50 T. Test for Water Tolerance of Aircraft Fuels,
D 1095 - 50 T. Test for Analysis of 60 Octane Number *Iso*octane—Normal Heptane ASTM Knock Test Reference Fuel Blends by Infrared Spetrophotometry, and
D 1096 - 50 T. Test for 1,3-Butadiene in C_4 Hydrocarbon Mixtures by Ultraviolet Spectrophotometry.

AMERICAN STANDARDS

Committee D-2 recommends that the following actions be recommended to ASA Sectional Committee Z11 on Petroleum Products and Lubricants:

(*1*) Consideration of Method D 217 - 52 T, which will replace D 217 - 48, as a suitable replacement for ASA Z11.3-1949.

(*2*) Consideration of Method D 721 - 51 T, Test for Oil Content of Paraffin Wax, which replaces D 721 - 47 (Z11.52-1948) for approval as American Standard.

(*3*) Consideration of all ASTM Standards which may be revised as a result of recommendations appearing in this report for continuation as American Standard in their revised form.

(*4*) Consideration of Methods D 1020, D 1023, D 1025, and D 1093, or such of these as may be made ASTM Standard, for approval as American Standard.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[19]

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, O. L. Maag.
First Vice-Chairman, L. C. Beard, Jr.
Second Vice-Chairman, H. M. Smith.
Secretary, W. T. Gunn.

This report has been submitted to letter ballot of the committee, which consists of 114 voting members; 64 members returned their ballots, of whom 63 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

O. L. MAAG,
Chairman.

W. T. GUNN,
Secretary.

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[19] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

COOPERATIVE STUDY OF NULL-PRESSURE TRANSMITTER FOR REID VAPOR PRESSURE TEST

The Proposed Manometric Method with Null Pressure Transmitter for Vapor Pressure Test of Petroleum Products, which appears in Appendix VIII,[1] was cooperatively tested by 13 laboratories on 8 fuel samples ranging from 3 to 16 lb. In these tests the Reid vapor pressure was determined with the null transmitter and the Bourdon gage. Duplicate determinations were made with each method. Included in the samples tested were two pure hydrocarbons, normal pentane (sample No. 2), and 2,3-dimethylbutane (sample No. 1).

The results of this testing program with respect to repeatability and reproducibility are shown in the table at the top of the next column.

Sample Number	Average Reid Vapor Pressure, psi		
	Null Transmitter	Bourdon Gage	Difference, Null-Bourdon
1	7.80	7.66	0.14
2	15.40	15.31	0.09
3	3.30	3.26	0.04
4	7.06	6.98	0.08
5	9.14	9.05	0.09
6	11.99	11.84	0.15
7	15.66	15.62	0.04
8	15.74	15.67	0.07
Repeatability	0.3	0.3	
Reproducibility	0.5	0.5	

This indicates that the precision with the null transmitter in this first series of tests was equal to that obtained with the Bourdon gage, a device in use for over 20 yr. It had been expected that the null transmitter would be basically superior to the Bourdon gage, and yield equal numerical values. It is obvious, however, that the consistently higher values obtained with the null transmitter must be due to an assignable cause, possibly the difference of volume capacity of the two instruments. Future work is planned to establish whether the failure of the testing program to verify these expectations was caused by equipment deficiencies, by newness of the apparatus and procedures, or by other causes.

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[1] See p. 377.

APPENDIX I

SUPPORTING DATA FOR THE ADOPTION OF THE CFR-48 CRANKCASE

Research Division I on Combustion Characteristics and its Section D on Test Equipment have given serious consideration to the status of the 1948 model high-speed ASTM-CFR crankcase shown in Fig. 1. As a consequence, the following recommendation was presented to Committee D-2: That the redesigned high-speed crankcase, designated CFR-48, be adopted as optional equipment for the following methods for rating fuels: Motor, D 357; Research, D 908; Aviation, D 614; Supercharge, D 909; and Cetane, D 613.[1]

The CFR-48 crankcase has resulted from the work of a panel formed in the Coordinating Research Council toward the end of World War II, having as its objective the design of a more rugged and more versatile crankcase than either the "low-speed" or "high-speed" designs. Two crankcases were built in 1945, one of which was exhibited to SAE in 1947 and to ASTM in 1948.

The original crankcase was placed in service at Waukesha on July 9, 1946. This crankcase has been operated 5,572 hr in Supercharge service, and has been used both for aviation fuel rating and for a variety of parts and accessory tests. All of Waukesha's ASTM exchange group testing on aviation fuels since 1947 has been done on this engine. There is no tabulation of these results available; however, another laboratory submitted Supercharge ratings on National Aviation Exchange Fuel samples from October, 1950, to January, 1952. These data are shown in Table I. It can be seen from these data that the crankcase had no significant effect on the ratings.

The second crankcase was put in service at Waukesha on September 8, 1948, as a Motor and Research unit. To date, 2,458 hr have been accumulated in rating many types of commercial fuels; and, in addition, 24 National Motor Fuel Exchange Group samples have been run by the Motor Method, and 19 by the Research Method. The record of the exchange ratings, together with the Exchange Group average deviations, are shown in Table II. In all ratings made—and a great many the first year were cross-checked by ratings on a "low-speed" crankcase unit—no constant rating difference could be noted.

Because a more rugged and versatile design has been accomplished, it is felt by the Division that the CFR-48 crank case is a very real improvement over the other two crankcases. Load and speed limitations have been raised; and provision has been made for easier field maintenance and for additional accessory drives. A general idea of the design can be obtained from Fig. 1.

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[1] ASTM Manual of Engine Test Methods for Rating Fuels, October, 1952.

TABLE I.—RATING PRECISION OBTAINED WITH THE CFR-48 CRANKCASE BY ASTM SUPERCHARGE METHOD, ON ASTM NATIONAL AVIATION EXCHANGE SAMPLES A-205 THROUGH A-223.

Comparison of Performance Number Ratings by National Exchange Group[a] and Sinclair.[b]

Sample Number	ASTM National Average Rating		Sinclair Rating		ASTM National Standard Deviation		Sinclair Deviation		Sinclair Standing[c]	
	Fuel-Air Ratio		Fuel-Air Ratio		Fuel-Air Ratio		Fuel-Air Ratio		Fuel-Air Ratio	
	0.095	Rich	0.095	Rich	0.095	Rich	0.095	Rich	0.095	Rich
A-205........	100.5	102.3	97.2	100.0	4.1	2.8	−3.3	−2.3	...	...
A-206........	128.5	130.9	127.2	131.2	3.1	1.0	−1.3	+0.3	15	12
A-207........	70.7	70.2	69.7	69.5	2.0	1.5	−1.0	−0.7	3	1
A-208........	145.7	145.9	145.7	145.4	1.3	1.0	0.0	−0.5	3	3
A-209........	142.8	142.1	143.1	142.8	0.9	1.4	+0.3	+0.7	5	3
A-210........	143.4	143.8	142.2	143.1	1.7	1.5	−1.2	−0.7	4	4
A-211........	125.2	129.3	127.6	129.6	3.4	1.5	+2.4	+0.3	4	2
A-212........	98.5	95.9	104.0	97.9	4.1	2.0	+5.5	+2.0	...	...
A-213........	130.5	130.6	131.8	130.8	2.4	1.6	+1.3	+0.2	8	3
A-214........	144.0	145.6	140.7	145.7	3.2	3.0	−3.3	+0.1	9	3
A-215........	81.7	85.2	80.2	84.6	2.6	1.4	−1.5	−0.6	9	2
A-216........	130.2	129.8	130.9	130.1	1.8	1.3	+0.7	+0.3	12	2
A-217........	123.3	128.8	123.3	127.5	6.0	2.3	0.0	−1.3	8	2
A-218........	96.9	93.2	98.6	93.3	3.2	1.6	+1.7	+0.1	8	1
A-219........	68.7	69.8	68.5	69.3	2.3	2.1	−0.2	−0.5	...	...
A-220........	145.0	145.4	145.4	145.8	1.5	0.8	+0.4	+0.4	7	1
A-221........	145.5	147.6	142.8	148.2	3.1	2.3	−2.7	+0.6	5	1
A-222........	143.7	144.5	143.9	146.6	1.5	1.3	+0.2	+2.1	3	2
A-223........	144.8	145.8	145.0	146.2	...	...	+0.2	+0.4	...	...

[a] ASTM National Aviation Exchange Group Results (October, 1950, through January, 1952).

[b] Sinclair Research Laboratories, Inc., Harvey, Ill.

[c] Standings based on last ten samples as stated in Bureau of Mines reports on exchange samples.

TABLE II.—RATING RESULTS TAKEN FROM NATIONAL EXCHANGE GROUP REPORTS.

RATINGS MADE ON UNIT NO. 139 EQUIPPED WITH CFR-48 CRANK CASE.

Sample Number	Average Octane Number by Motor Method	Deviation, Unit 139	Average Group Deviation	Average Research Octane Number	Deviation, Unit 139	Group Average Deviation
R-370.....	75.6	−0.6	±0.3	...	...	...
R-371.....	71.4	+0.1	±0.4	79.6	+0.6	±0.5
R-372.....	76.6	−0.4	±0.32	82.5	+0.1	±0.23
R-373	81.9	−1.4	±0.59	95.1	−0.3	±0.25
R-374.....	...	...	...	90.7	0.0	±0.34
R-375.....	...	...	...	87.1	−0.3	±0.33
R-376.....	81.9	+0.2	±0.35	92.0	+0.1	±0.22
R-377.....	74.7	+0.1	±0.48	82.0	+1.0	±0.55
R-378.....	75.0	−0.4	±0.33	80.1	+0.1	±0.37
R-379.....	77.1	−0.2	±0.23	77.9	+0.1	±0.21
R-380.....	79.5	+0.5	±0.57	93.8	+0.2	±0.37
R-381.....	...	...	...	86.2	+0.2	±0.14
R-383.....	80.7	−0.3	±0.30	86.9	−0.4	±0.22
R-384.....	70.0	+0.1	±0.53	74.7	+0.3	±0.30
R-385.....	81.0	−0.7	±0.34	87.6	+0.4	±0.26
R-386.. .	80.7	−0.2	±0.31	90.0	+.02	±0.19
R-387 ...	74.9	+0.9	±0.39	85.3	+.06	±0.40
R-392.....	82.0	0.0	±0.32	...	...	...
R-393.....	82.5	−0.8	±0.43	...	...	...
R-395.....	78.6	+0.5	±0.24	86.0	+0.2	±0.14
R-396.....	73.8	+0.9	±0.36	83.2	+0.2	±0.30
R-397. .	72.5	+0.5	±0.48	...	...	...
R-399	86.7	−0.2	±0.30	92.9	0.0	±0.27
R-400.....	81.5	0.0	±0.37	...	...	...
R-402.....	82.8	−0.4	±0.29	...	...	...
R-403.....	76.1	−0.3	±0.32	...	...	...
R-404.....	Iso + 0.07	−0.03	±0.04	...	...	...

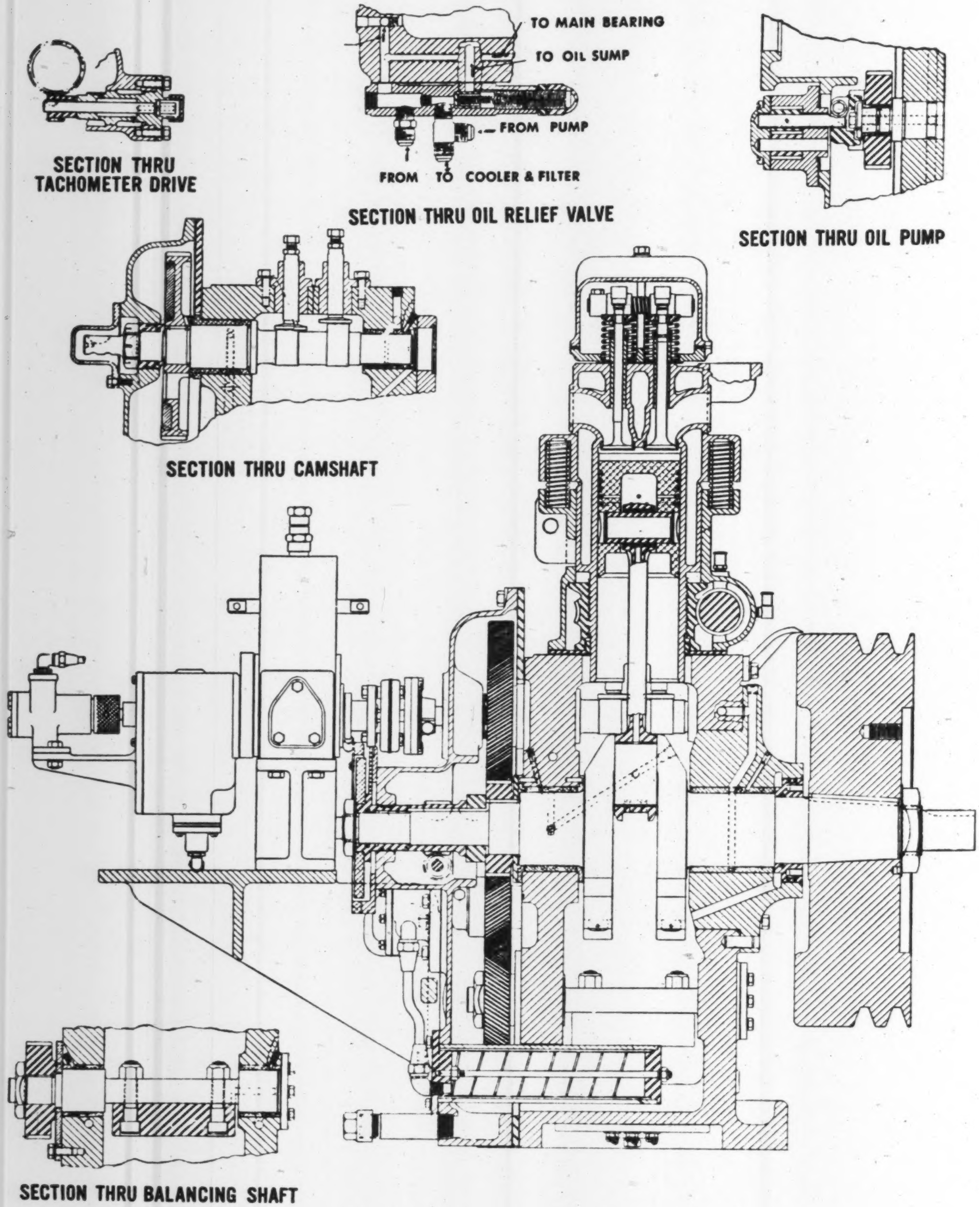
SECTION THRU TACHOMETER DRIVE
TO MAIN BEARING
TO OIL SUMP
FROM PUMP
FROM
TO COOLER & FILTER
SECTION THRU OIL RELIEF VALVE
SECTION THRU OIL PUMP
SECTION THRU CAMSHAFT
SECTION THRU BALANCING SHAFT

FIG. 1.—1948 Model High-Speed ASTM-CFR Crankcase.

APPENDIX II

PROPOSED METHOD OF TEST FOR API GRAVITY OF PETROLEUM AND ITS PRODUCTS BY HYDROMETER[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes a procedure for the determination by means of a glass hydrometer of the API gravity (in vacuum) of crude petroleum and of petroleum products normally handled as liquids and having a Reid vapor pressure of 26 lb or less. Results are determined at 60 F, or converted to values at 60 F, by means of standard Tables.

NOTE 1.—Procedure for determination of gravity of road oils, road tars, asphalt cements, and soft tar pitches at 25 C is given in ASTM Method D 70.[3]

Definition

2. *API Gravity* is defined by the following equation:

$$\text{API Gravity, deg} = \frac{141.5}{\text{sp gr } 60/60 \text{ F}} - 131.5$$

Apparatus

3. The following apparatus is required:

(*a*) *Hydrometers*,[4] of glass, graduated in degrees API (in vacuum), and conforming to the Proposed Specifications for ASTM Hydrometers[4] for hydrometers of series 1H through 10H having 12° API scales, series 21H through 40H having 6° API scales; also thermohydrometers of series 51H through 60H having 12° API scales, and of series 71H through 73H having 12° API scales, all with maximum scale errors of 0.1° API.

NOTE.—Specifications for hydrometers with 12° API scales with thermometers incorporated in the body or in the stem (thermo-hydrometers), are in preparation.

(*b*) *Thermometers*, having a range of −5 to +215 F and conforming to the requirements for Thermometer 12F as prescribed in ASTM Specifications E 1.[5]

(*c*) *Hydrometer Cylinders*, made of metal, clear glass, or plastic. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 25 mm greater than the outside diameter of the hydrometer used in it. The height of the cylinder shall be such that the length of the column of sample it contains is greater by at least 25 mm than the portion of the hydrometer which is immersed beneath the surface of the sample.

Temperature of Test

4. The gravity determined by the hydrometer method is most accurate at or near the standard temperature of 60 F:

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952. This method and the Proposed Method for Specific Gravity, see p. 350, are a proposed revision and separation of Standard Method D 287, see 1949 Book of ASTM Standards, Part 5.

[3] 1952 Book of ASTM Standards, Part 3.

[4] See p. 527.

[5] 1951 Supplement to Book of ASTM Standards, Part 5.

use this or any other temperature between 0 and 195 F for test so far as it is consistent with the type of sample and necessary limiting conditions shown in Table I.

Procedure

5. (*a*) Adjust the temperature of the sample in accordance with Table I. The hydrometer cylinder and thermometer shall be at approximately the same temperature as the sample to be tested.

TABLE I.—LIMITING CONDITIONS AND TEST TEMPERATURES.

Sample Type	Gravity Limits	Initial Boiling Point Limits	Other Limits	Test Temperature
Highly volatile	Lighter than 70° API	...	...	Cool to 35 F or lower in original closed container
Moderately volatile	Heavier than 70° API	Below 250 F	...	Cool to 65 F or lower in original closed container
Moderately volatile and viscous	Heavier than 70° API	Below 250 F	Viscosity too high at 65 F	Heat to minimum temperature for sufficient fluidity
Nonvolatile	Heavier than 70° API	Above 250 F	...	Any temperature between 0 and 195 F as convenient
Mixtures of non-petroleum with petroleum products	...	...	...	60 ± 0.25 F

(*b*) Pour the sample into the clean hydrometer jar without splashing, so as to avoid the formation of air bubbles and to reduce to a minimum the evaporation of the lower-boiling constitutents of the more volatile samples. For the more volatile samples, transfer to the hydrometer cylinder by siphoning. Remove any air bubbles formed, after they have collected on the surface of the sample, by touching them with a piece of clean filter paper before inserting the hydrometer. Place the cylinder containing the sample in a vertical position in a location free from air currents. Take precautions to prevent the temperature of the sample from changing appreciably during the time necessary to complete the test. During this period, the temperature of the surrounding medium should not change by more than 5 F.

(*c*) Lower the hydrometer gently into the sample and, when it has settled, depress it about two scale divisions into the liquid and then release; keep the rest of the stem dry, as unnecessary liquid on the stem changes the effective weight of the instrument, and so affects the reading obtained. With samples of low viscosity, a slight spin imparted to the instrument on releasing assists in bringing it to rest, floating freely away from the walls of the hydrometer cylinder. Allow sufficient time for the hydrometer to become completely stationary and for all air bubbles to come to the surface. This is particularly necessary in the case of the more viscous samples.

(*d*) When the hydrometer has come to rest, floating freely, and the temperature of the sample is constant to 0.2 F, read the hydrometer to the nearest half-scale division. The correct reading is that point on the hydrometer scale at which the surface of the liquid cuts the scale. Determine this point by placing the eye slightly below the level of the liquid and slowly raising it until the surface, first seen as a distorted ellipse, appears to become a straight line cutting the hydrometer scale.

(*e*) To make a reading with nontransparent oils, observe the point on the hydrometer scale to which the sample rises above its main surface, placing the eye slightly above the plane surface of the liquid. This reading requires a correction. Determine this correction for the particular hydrometer in use by observing the height above the main surface of the liquid to which the oil rises on the hydrometer scale when the hydrometer in question is immersed in a transparent oil having a surface tension similar to that of the sample under test.

(*f*) Observe the temperature of the sample to the nearest 0.25 F immediately before and after the observation of the gravity, the liquid in the cylinder being thoroughly but cautiously stirred with the thermometer, the whole of the mercury thread being immersed. Should these temperature readings differ by more than 1 F, repeat the temperature and gravity observations when the temperature of the sample has become more stable. Record the mean of the thermometer reading before and after the final hydrometer reading, to the nearest degree Fahrenheit, as the temperature of the test.

NOTE 2.—When thermo-hydrometers are used, stir the sample by carefully raising and lowering the hydrometer. It is satisfactory in this case to read the thermometer scale after the hydrometer reading has been observed. Because the thermometer incorporated in the hydrometer possesses certain inherent defects of design, the precision of the reported value will be poorer than that described in Section 7.

Calculation

6. (*a*) When gravities have been observed on opaque liquids by the procedure given in Section 5(*e*), subtract the correction in degrees API from the hydrometer reading observed.

(*b*) Correct all hydrometer readings to 60 F, using Table 5, "Reduction of Observed API Gravity to API Gravity at 60°F," of the ASTM-IP Petroleum Measurement Tables (American Edition).[6]

The interconversion of API gravity to specific gravity is given in Table 3, "API Gravity at 60° F to Specific Gravity at 60° F and to Density at 15° C" of the ASTM-IP Petroleum Measurement Tables (American Edition).[6]

Precision

7. The following criteria should be used for judging the acceptability of results obtained at temperatures differing from 60 F by less than 18 F:

	Repeatability	**Reproducibility**
	Duplicate Results by the Same Operator	Average of Two Results in Each of Two Laboratories
Degree API.......	0.1	0.5

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[6] Published jointly by, and available from, the American Society for Testing Materials, 1916 Race St., Philadelphia 3, and the Institute of Petroleum, 26 Portland Place, London W-1. Companion volumes—the British Edition and the Metric Edition—are also available. These tables supersede all other similar tables previously published by either of these Societies.

APPENDIX III

PROPOSED METHOD OF TEST FOR SPECIFIC GRAVITY OF PETROLEUM AND ITS PRODUCTS BY HYDROMETER[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes a procedure for the determination by means of a glass hydrometer of the specific gravity (in vacuum) of crude petroleum and of petroleum products normally handled as liquids, and having a Reid vapor pressure of 26 lb or less. Results are determined at 60 F, or converted to values at 60 F, by means of standard Tables.

Note 1.—Procedure for determination of gravity of road oils, road tars, asphalt cements, and soft tar pitches at 25 C is given in ASTM Method D 70.[3] ASTM Method D 891[3a] describes a variety of methods for the determination of the specific gravity 15.56/15.56 C of industrial aromatic hydrocarbons.

Definition

2. *Specific Gravity* is the ratio of weight of a given volume of material to the weight of an equal volume of water. In this method both weights are corrected to weight in vacuum, and the standard reference temperature for both material and water is 60 F.

Apparatus

3. The following apparatus is required:

(*a*) *Hydrometers*,[4] of glass, graduated in specific gravity at 60/60 F (in vacuum), and conforming to the Proposed Specifications for ASTM Hydrometers.[4]

Note.—Specifications for hydrometers with 0.050 specific gravity scales with thermometers incorporated in the body or in the stem (thermohydrometers), are in preparation.

(*b*) *Thermometers*, having a range of −5 to +215 F and conforming to the requirements for Thermometer 12 F as prescribed in ASTM Specifications E 1.[5]

(*c*) *Hydrometer Cylinders*, of metal, clear glass, or plastic. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 25 mm greater than the outside diameter of the hydrometer used in it. The height of the cylinder shall be such that the length of the column of sample it contains is greater by at least 25 mm than the portion of the hydrometer which is immersed beneath the surface of the sample.

Temperature of Test

4. The gravity determined by the hydrometer method is most accurate at or near the standard temperature of 60 F; use this or any other temperature between 0 and 195 F for test, so far as it is

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952. This method and the Proposed Method for API Gravity, see p. 347, are a proposed revision and separation of Standard Method D 287, 1949 Book of ASTM Standards, Part 5.

[3] 1949 Book of ASTM Standards, Part 5.

[3a] 1949 Book of ASTM Standards, Part 3.

[4] See p. 527.

[5] 1951 Supplement to Book of ASTM Standards, Part 5.

consistent with the type of sample and necessary limiting conditions shown in Table I.

Procedure

5. (*a*) Adjust the temperature of the sample in accordance with Table I. The hydrometer cylinder and thermometer shall be at approximately the same temperature as the sample to be tested.

(*b*) Pour the sample into the clean hydrometer jar without splashing, so as to avoid the formation of air bubbles and to reduce to a minimum the evaporation of the lower-boiling constituents of the more volatile samples. For the more volatile samples, transfer to the hydrometer cylinder by siphoning. Remove any air bubbles formed, after they have collected on the surface of the sample, by touching them with a piece of clean filter paper before inserting the hydrometer. Place the cylinder containing the sample in a vertical position in a location free from air currents. Take precautions to prevent the temperature of the sample from changing appreciably during the time necessary to complete the test. During this period, the temperature of the surrounding medium should not change by more than 5 F.

(*c*) Lower the hydrometer gently into the sample and, when it has settled, depress it about two scale divisions into the liquid and then release; keep the rest of the stem dry, as unnecessary liquid on the stem changes the effective weight of the instrument, and so affects the reading obtained. With samples of low viscosity, a slight spin imparted to the instrument on releasing assists in bringing it to rest, floating freely away from the walls of the hydrometer cylinder. Allow sufficient time for the hydrometer to become completely stationary and for all air bubbles to come to the surface. This is particularly necessary in the case of the more viscous samples.

TABLE I.—LIMITING CONDITIONS AND TEST TEMPERATURES.

Sample Type	Gravity Limits	Initial Boiling Point Limits	Other Limits	Test Temperature
Highly volatile	Lighter than 0.70 sp gr	...	...	Cool to 35 F or lower in original closed container
Moderately volatile	Heavier than 0.70 sp gr	Below 250 F	...	Cool to 65 F or lower in original closed container
Moderately volatile and viscous	Heavier than 0.70 sp gr	Below 250 F	Viscosity too high at 65 F	Heat to minimum temperature for sufficient fluidity
Nonvolatile	Heavier than 0.70 sp gr	Above 250 F	...	Any temperature between 0 and 195 F as convenient
Mixtures of non-petroleum with petroleum products	...	...	...	60 ± 0.25 F

(*d*) When the hydrometer has come to rest, floating freely, and the temperature of the sample is constant to 0.2 F, read the hydrometer to the nearest half-scale division. The correct reading is that point on the hydrometer scale at which the surface of the liquid cuts the scale. Determine this point by placing the eye slightly below the level of the liquid and slowly raising it until the surface, first seen as a distorted ellipse, appears to become a straight line cutting the hydrometer scale.

(*e*) To make a reading with nontransparent oils, observe the point on the hydrometer scale to which the sample rises above its main surface, placing the eye slightly above the plane surface of the liquid. This reading requires a correction. Determine this correction for the particular hydrometer in use by observing the height above the main surface of the liquid to which the oil rises on the hydrometer scale when the hydrometer in question is immersed in a transparent oil having a surface tension similar to that of the sample under test.

(*f*) Observe the temperature of the sample to the nearest 0.25 F immediately before and after the observation of the gravity, the liquid in the cylinder being thoroughly but cautiously stirred with the thermometer, the whole of the mercury thread being immersed. Should these temperature readings differ by more than 1 F, repeat the temperature and gravity observations when the temperature of the sample has become more stable. Record the mean of the thermometer reading before and after the final hydrometer reading, to the nearest degree Fahrenheit, as the temperature of the test.

NOTE 2.—When thermo-hydrometers are used, stir the sample by carefully raising and lowering the hydrometer. It is satisfactory in this case to read the thermometer scale after the hydrometer reading has been observed. Because the thermometer incorporated in the hydrometer possesses certain inherent defects of design, the precision of the reported value will be poorer than that described in Section 7.

Calculation

6. (*a*) When gravities have been observed on opaque liquids by the procedure given in Section 5 (*e*), add the correction for specific gravity to the hydrometer reading observed.

(*b*) Correct all hydrometer readings to 60 F, using Table 23, "Reduction of Observed Specific Gravity to Specific Gravity at 60° F," of the ASTM-IP Petroleum Measurement Tables (American Edition).[6]

The interconversion of specific gravity to API gravity is given in Table 21, "Specific Gravity at 60° F to Density at 15° C and to API Gravity at 60° F," of the ASTM-IP Petroleum Measurement Tables (American Edition).[6]

Precision

7. The following criteria should be used for judging the acceptability of results obtained at temperatures differing from 60 F by less than 18 F:

	Repeatability Duplicate Results by the Same Operator	**Reproducibility** Average of Two Results in Each of Two Laboratories
Specific gravity....	0.0003	0.0005

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[6] Published jointly by, and available from, the American Society for Testing Materials, 1916 Race St., Philadelphia 3, and the Institute of Petroleum, 26 Portland Place, London W-1. Companion volumes—the British Edition and the Metric Edition—are also available. These tables supersede all other similar tables previously published by either of these Societies.

APPENDIX IV

PROPOSED METHOD OF TEST FOR HYDROCARBON TYPES IN JET PROPULSION FUELS[1, 2]

FLUORESCENT-INDICATOR ADSORPTION (FIA) METHOD

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes a procedure for determination of the aromatics, olefins, and saturates in aircraft gas turbine and jet propulsion fuels with end points not exceeding 600 F. Compounds containing sulfur, nitrogen, or oxygen are determined as aromatics. Dark materials sometimes require distillation to remove interfering colored components.

NOTE 1.—A more accurate procedure for the determination by chromatography of the aromatic content of olefin-free gasoline or gasoline fractions appears in ASTM Method D 936.[3]

Outline of Method

2. Approximately $\frac{3}{4}$ ml of sample containing traces of an added fluorescent dye mixture is introduced into a small glass adsorption column with a long, narrow extension and packed with fine activated silica gel. When all the sample has been adsorbed on the gel, alcohol is added to desorb and force the sample down the column. The hydrocarbons are separated according to their adsorption affinities into aromatics (including aromatics with olefinic side chains plus any sulfur, nitrogen, and oxygen compounds), olefins, and saturates. The fluorescent dyes are also selectively separated with the sample fractions, and make the boundaries of the aromatics, olefins, and saturates clearly visible under ultraviolet light. The volume percentage of each hydrocarbon type is determined by measuring the length of each zone in the long, narrow extension of the column.

Apparatus

3. It is very desirable to mount the apparatus assembly described below in a dark-room or darkened area to facilitate observation of zone boundaries. For multiple determinations, a manifold air pressure system with several stainless steel or glass inner spherical joints to accommodate a series of columns is a convenient arrangement.

(*a*) *"Standard" Adsorption Column*, made of glass and consisting of a charger section with a capillary neck, a separator section, and an analyzer section, constructed as shown on the left in Fig. 1; alternatively the "true bore" column described in Note 2 may be used. To fasten the separator to the analyzer section, heat one end of the latter in a small gas flame until it is just hot enough to melt Tygon. Insert this end halfway into a 3-cm section of Tygon tubing and compress the tubing around the glass until a

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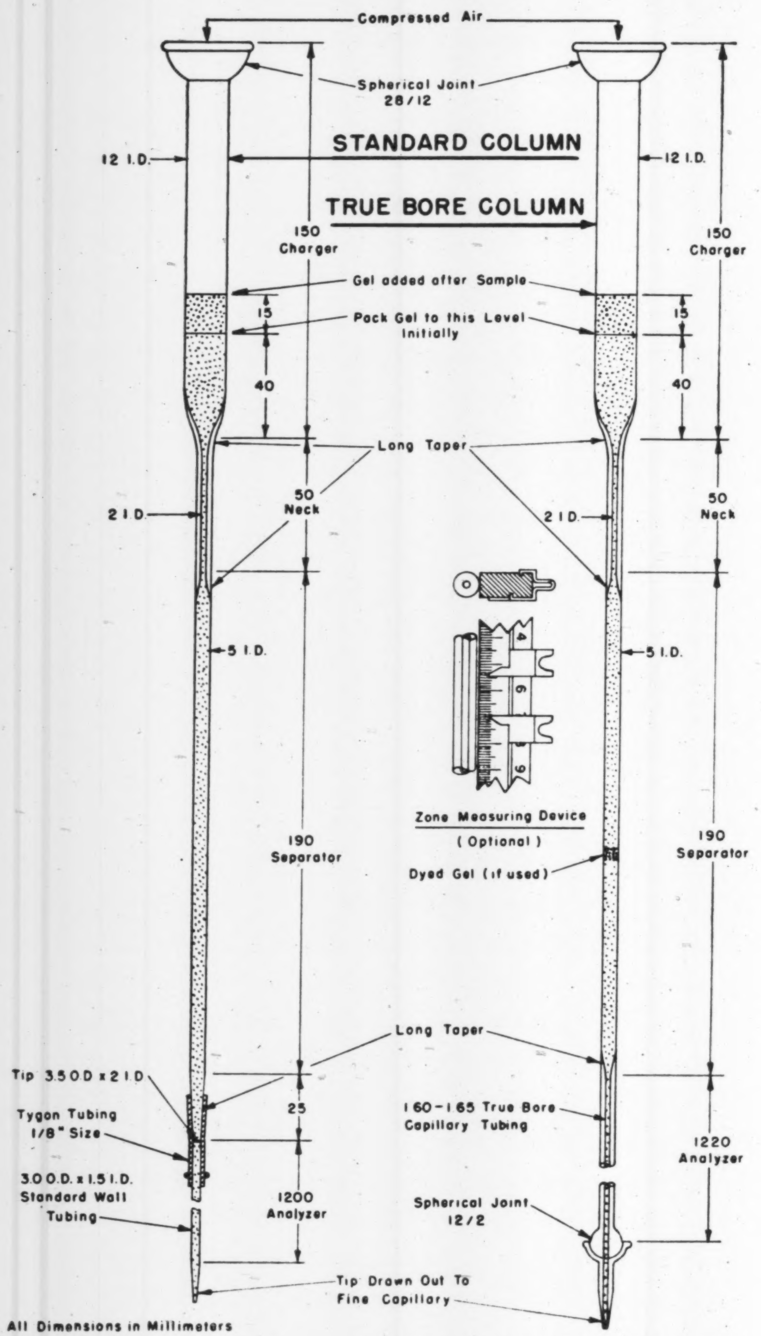
[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952.

[3] 1951 Supplement to Book of ASTM Standards, Part 5.


Compressed Air
Spherical Joint 28/12
STANDARD COLUMN
TRUE BORE COLUMN
12 I.D.
12 I.D.
150 Charger
150 Charger
Gel added after Sample
Pack Gel to this Level Initially
15
15
40
40
Long Taper
50 Neck
50 Neck
2 I.D.
2 I.D.
5 I.D.
5 I.D.
Zone Measuring Device (Optional)
4
6
6
190 Separator
190 Separator
Dyed Gel (if used)
Long Taper
Tip 3.5 O.D x 2 I.D
Tygon Tubing 1/8" Size
3.0 O.D. x 1.5 I.D. Standard Wall Tubing
25
1.60-1.65 True Bore Capillary Tubing
1220 Analyzer
1200 Analyzer
Spherical Joint 12/2
Tip Drawn Out To Fine Capillary

All Dimensions in Millimeters

FIG. 1.—Adsorption Columns with Standard Wall (left) and True Bore (right) Tubing in Analyzer Section.

glass-to-Tygon seal is obtained. Secure this seal further by wrapping it tightly with soft brass wire. Insert the tip of the separator section into this Tygon joint, forcing it in until it touches the end of the analyzer section; draw out the other end of the analyzer section to a fine capillary to retain the gel. The success of the test depends largely on the uniformity of the bore of the tubing selected for the analyzer section (see Note 2) and, to provide a check on such uniformity, the use of duplicate tubes is required for each test. Calibrations of this tubing would be impractical; however, any significant variation in the outside diameter along the tube may be taken as an indication of irregularities in the inner diameter and such tubing should not be used.

NOTE 2.—To avoid duplicate tests and inspection of all analyzer tubing for irregularities in bore diameters, the "true bore" column[4] assembled as shown on the right in Fig. 1 may be used. The inner diameter of the analyzer section should be 1.60 to 1.65 mm and an approximately 100-mm "thread" of mercury (as measured by ordinary calipers) should not vary by more than 0.3 mm in any part of the analyzer section. In glass-sealing the various sections to each other, long taper connections should be made instead of shouldered connections. The silica gel is upheld by a short piece of capillary tubing connected by a spherical joint as shown.

(*b*) *Zone Measuring Device.*—The zones may simply be marked with a glass-writing pencil and the distances measured with a meter rule, making the measurement with the disconnected analyzer section of the standard column (Fig. 1) lying horizontally on the bench.

NOTE 3.—For a permanent assembly, and required when true bore tubing is used, it is desirable to have wooden meter rules fastened at the same distance from the wall of the darkroom as the manifold air pressure system. Also it is convenient to have each rule fitted with four movable metal index clips (see Fig. 1) for marking of zone boundaries and measurement of the length of each zone. Very narrow zones may be marked off by employing a pair of clips, one of which is the mirror image of the other.

(*c*) *Ultraviolet Light Source*, with radiation predominantly at 3650 Å is required; an ordinary "mineral lamp" or any commercial "black light" source is satisfactory. A convenient arrangement consists of one or two 36-in. "black light" units mounted vertically along the apparatus.

(*d*) *Vibrator*, for packing of the silica gel. A small electric vibrator as used by barbers is recommended but other means of vibrating as by tapping with a rubber covered rod or rubbing with a coarse file may be used.

Materials

4. (*a*) *Silica Gel*, 100- to 200-mesh manufactured to insure minimum olefin polymerization.[5]

(*b*) *Fluorescent Indicator*,[6] consisting of a mixture of Sudan III together with an olefin and aromatic dye dissolved in xylene. The mixed dye should be well stirred before use.

NOTE 4.—To facilitate adding the proper amount of dye, it is convenient to use a previously prepared dyed gel and add a 3- to 5-mm layer in the middle of the separator section as shown in Fig. 1 for the "true bore" column. To prepare a stock of dyed gel, dissolve 200 mg of the well-stirred fluorescent-indicator dye solution in about 150 ml of ether and add 50 g of the specified silica gel to make a slurry. Remove the ether slowly by evaporation and distill off the xylene of the dye solution at approximately 50 C and 1 mm pressure. Store the dyed gel in the dark and under nitrogen.

(*c*) *Isopropyl Alcohol*, refined 99 per cent, conforming to ASTM Specifications D 770.[7]

(*d*) *Pressuring Gas.*—Air (or nitrogen) delivered to the top of the column at a pressure of about 15 psi.

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[4] Columns with true bore analyzer section constructed specifically for this test are available from Rankin Glass Blowing Co., 3990 Franklin Canyon Road, Martinez, Cal. True bore tubing is also available from Fischer and Porter Co., 96 Countyline Road, Hatboro, Pa.

[5] Available from Davison Chemical Corp., Baltimore 3, Md., by specifying Code 923.

[6] The dye, mixed for this method, is available from Patent Chemicals, Inc., 335 McLean Boulevard, Patterson 4, N. J., by requesting "Dye Mixture for the FIA Method of Hydrocarbon Type Analysis."

[7] 1949 Book of ASTM Standards, Part 4.

Procedure

5. (*a*) Owing to small variations in bore of different analyzer tubings, prepare two columns for simultaneous testing if the "standard" column is used or a single column if true bore column is employed. (A single "standard" column may, of course, be used for routine work where the error of variation in bore of standard wall tubing is of no consequence.) Suspend the column freely from a loose-fitting clamp placed immediately below the spherical joint of the charger section. Pour the specified silica gel into the column through a glass funnel until the required amount has been added (see Note 5). While supporting the fragile analyzer lightly with the palm of the hand, vibrate or tap the column to pack the gel firmly. (Packing is conveniently done by using a small electric vibrator, applying the vibrator up and down the tubing.) Add more of the specified silica gel until the tightly packed gel extends approximately 40 mm into the charger section (a 5-min vibration period is usually satisfactory when the electrical vibrator is used). Connect the filled column to the air manifold, and when a permanently mounted meter rule is used, as required for the true bore column, fasten the lower end of the column to the fixed rule by means of a rubber band.

NOTE 5.—When using dyed gel (see Note 4), add the regular gel until the separator section is half full, then add a 3- to 5-mm layer of dyed gel. Add more gel and vibrate the column until it is firmly packed to the point described above.

(*b*) Mix the fluorescent dye mixture and the sample in a volume ratio of approximately 1 to 1000 using the tip of a needle to transfer the dye. As little as 0.5 parts per 1000 is sufficient for ready detection; above 5 parts per 1000, however, the xylene content of the dye mixture may observably alter the results.

(*c*) Add, by means of a 1-ml pipet, 0.75 ± 0.03 ml of sample to the top of the gel. Cover immediately with an approximately 15-mm layer of additional gel to soak up the sample, and tamp well with a glass rod. Samples containing an unusual amount of light ends should be cooled in an ice bath prior to analysis and measured with a cooled pipet. The analysis of dark colored samples is frequently facilitated by subjecting the sample to vacuum distillation prior to test to remove colored impurities which interfere with the reading of the zones in the analyzer section.

(*d*) Fill the charger section to the spherical joint with isopropyl alcohol and apply a gas pressure of about 15 psi to move the liquid front down the column. For jet propulsion fuels the transit time through the column should be about 45 min and for lighter samples somewhat less.

(*e*) After the red alcohol-aromatic boundary has advanced 200 to 250 mm into the analyzer section, quickly mark the boundary of each hydrocarbon type zone observed in ultraviolet light in the following sequence (**Caution:** Take great care not to touch the column with the hands during this operation): For the non-fluorescent saturate zone, mark the front of the charge and the point where the yellow fluorescence first reaches its maximum intensity; for the upper end of the second, or olefin, zone, mark the point where the blue fluorescence first reaches its maximum intensity; finally, for the upper end of the third, or aromatic, zone, mark the upper end of a reddish or brown zone. With colorless distillates, the alcohol-aromatic boundary is clearly defined by a red ring of Sudan III dye. However, impurities in cracked fuels often obscure this red ring and give a brown coloration, which varies in length, but which should always be counted as a part of the aromatic zone.

(*f*) When the sample has advanced

another 100 to 150 mm down the column, again mark the zones as described above. If the marking has been made with a glass-writing pencil, two colors can be used to mark off each set of measurements and the distances measured at the end of the test with the analyzer section lying horizontally on the bench top. If the boundaries have been marked off with index clips, the first set of measurements must be recorded before the second group is made.

NOTE 6.—If, when the "true bore" column is used, the total length of the three zones is less than 500 mm, the test is unsatisfactory. Such erratic results may be due to improper packing of the gel, improper glass sealing or incomplete elution of hydrocarbons by the alcohol. In the latter case, for higher boiling range samples, the use of isoamyl alcohol is recommended.

(*g*) Release the air pressure and disconnect the column. Discard the analyzer section after all measurements have been completed if the "standard" column is used. To remove used gel from the "true bore" column, invert it above a sink and insert through the wide end a long piece of No. 19 gage hypodermic tubing with a 45-deg angle tip. By means of a $\frac{1}{4}$-in. copper tubing at the opposite end for attaching a rubber tube, connect to a water tap and flush with a rapid stream of water. Rinse with acetone and dry by evacuation.

Calculation

6. (*a*) Calculate the percentage by volume of each hydrocarbon type as follows:

$$\text{Aromatics, per cent by volume} = \frac{L_a}{L} \times 100$$

$$\text{Olefins, per cent by volume} = \frac{L_o}{L} \times 100$$

$$\text{Saturates, per cent by volume} = \frac{L_s}{L} \times 100$$

where:

L_a = length of the aromatic zone, in millimeters,

L_o = length of the olefin zone, in millimeters,

L_s = length of the saturate zone, in millimeters, and

L = sum of $L_a + L_o + L_s$

(*b*) If the "standard" column has been used, report as the test result the average of the four sets of observations obtained from the two successive sets of readings on each of a pair of columns. If the "true bore" column has been used, report as the test result the average calculated from two successive sets of readings on a single column.

Precision

7. (*a*) Duplicate test results by the same operator should not differ by more than the following amounts:

	Repeatability
Aromatics	1.5
Olefins	1.5
Saturates	1.0

(*b*) The average of two results obtained in each of two laboratories should not differ by more than the following amounts:

	Reproducibility
Aromatics	2.5
Olefins	2.5
Saturates	2.0

APPENDIX V

PROPOSED METHOD OF TEST FOR WATER IN PETROLEUM AND BITUMINOUS PRODUCTS[1,2]

This proposed method is a proposed revision of ASTM Method D 95 - 46[3] and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes a procedure for the determination of water in petroleum products and in bituminous materials. The method is applicable to a variety of materials, but is particularly suitable for the determination of water in crude petroleum, fuel oil, road oil, cutback asphalt, liquid asphalt, asphalt emulsions, coal tar, water-gas tar, coke-oven tar, and other petroleum products or bituminous materials.

NOTE 1.—This method, with or without modification, is sometimes used for the determination of water in grease. The desirability of recommending that this method replace the procedure described in the Standard Methods D 128,[4] for Analysis of Grease is under consideration. For the determination of water in petroleum products by means of the centrifuge, see ASTM Method D 96.[5]

Outline of Method

2. The sample, mixed with a solvent, is placed in a glass or metal still provided with a reflux condenser discharging into a graduated trap connected to the still. Heat is applied, the contents of the still are boiled, and the vapor from the solvent, mixed with water vapor, is liquefied in the condenser. The water collects in the bottom of the trap, and the excess solvent runs back into the still, where it is again vaporized, carrying over an additional quantity of water. The boiling is continued until there is no further increase in the quantity of water in the trap, and the volume is recorded.

NOTE 2.—This method involves the essential features of the method as originally published,[6] but includes additional variations of apparatus and procedure.

Apparatus

3. The apparatus shall consist of the following:

(*a*) *Glass or Metal Still*, constructed as shown in Figs. 1 and 2 and specified in the Supplement, Sections A1 and A2.

(*b*) *Condenser*, Liebig straight-tube type, as shown in Figs. 1 and 2 and specified in the Supplement, Section A3.

(*c*) *Traps*, of 10- and 25-ml capacity, as required by the water content of the sample, constructed in accordance with Fig. 3 and calibrated as described in the Supplement, Section A4.

(*d*) *Heater*.—Any suitable gas burner or electric heater may be used with the glass still. With the metal still, a ring gas burner, having an inside diameter of 4 in. (100 mm) should be used.

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952.

[3] 1949 Book of ASTM Standards, Parts 3, 4, 5.

[4] 1949 Book of ASTM Standards, Part 5.

[5] 1950 Supplement to Book of ASTM Standards, Part 5.

[6] Dean and Stark, *Industrial and Engineering Chemistry*, Vol. 12, p. 486 (1920).

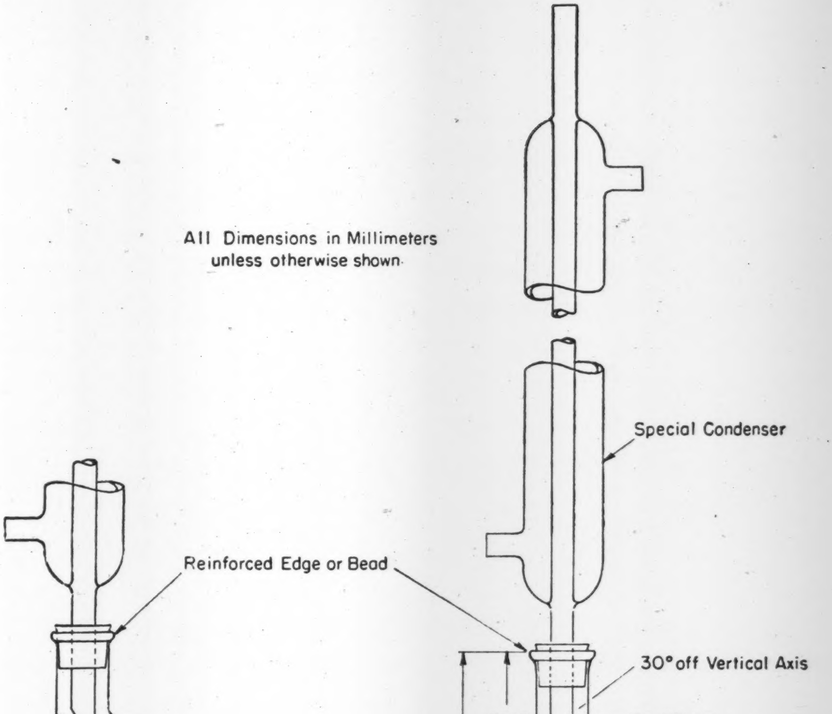
All Dimensions in Millimeters unless otherwise shown
Special Condenser
Reinforced Edge or Bead
30° off Vertical Axis
70±3
25-28 O.D.
15°±3
165±5
Metal Still to be of Copper or Brass
1" Opening
50±3
14-15 I.D.
15-18 O.D.
150±5
35±3
32±3
150±5
95±5
500 ml. Glass Flask Short Neck-Round Bottom

FIG. 1.—Apparatus for Determining Water in Petroleum and Bituminous Products.

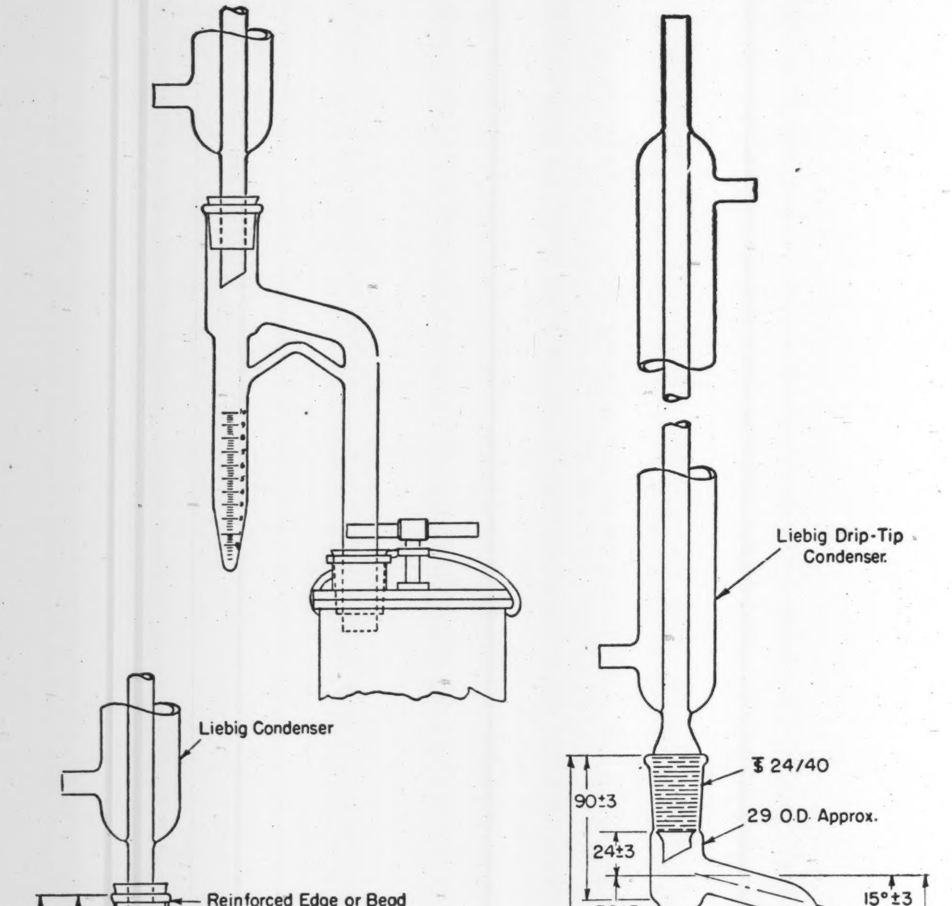
Liebig Drip-Tip Condenser.
Liebig Condenser
Reinforced Edge or Bead
70±3
25-28 O.D.
38±3
190±5
32±3
All Dimensions in millimeters unless otherwise shown.
$ 24/40
90±3
29 O.D. Approx.
24±3
15°±3
38±3
35°±5
205±5
50±3
14-15 I.D.
15-18 O.D.
173±5
35±3
$24/40
32±3
500 ml. Glass Flask Short Neck-Round Bottom

FIG. 2.—Construction Details of Condensers.

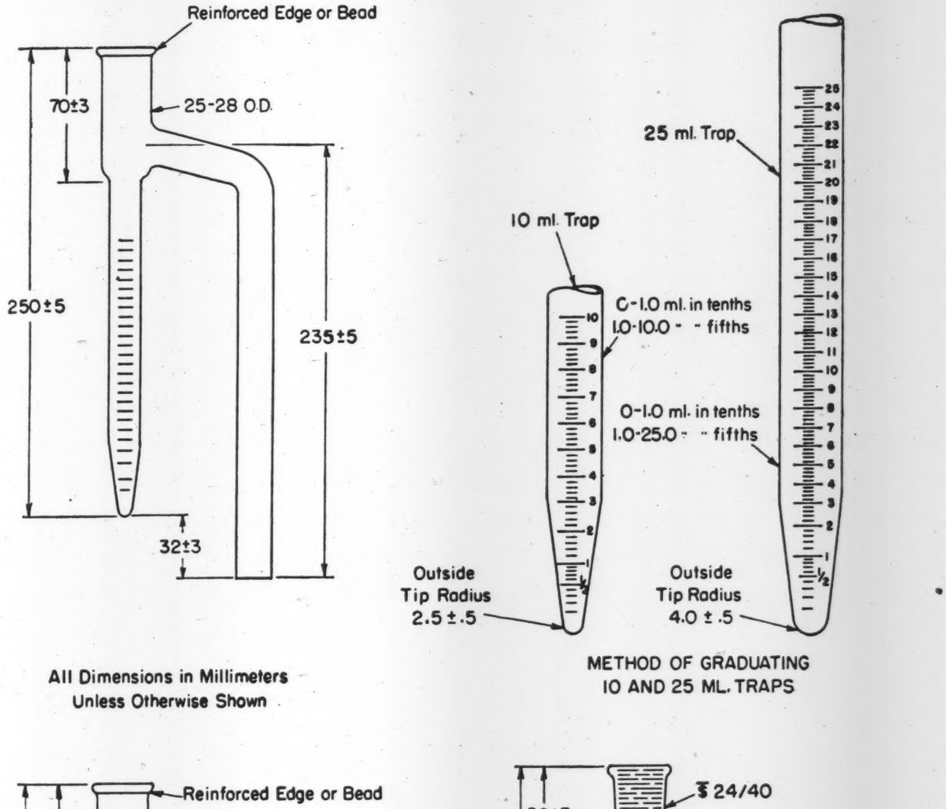
Reinforced Edge or Bead
70±3
25-28 O.D.
250±5
235±5
32±3
10 ml. Trap
25 ml. Trap
0-1.0 ml. in tenths
1.0-10.0 " " fifths
0-1.0 ml. in tenths
1.0-25.0 " " fifths
Outside Tip Radius 2.5 ± .5
Outside Tip Radius 4.0 ± .5
METHOD OF GRADUATING 10 AND 25 ML. TRAPS
All Dimensions in Millimeters Unless Otherwise Shown
Reinforced Edge or Bead
70±3
25-28 O.D.
38±3
265±5
250 ±5
32±3
90±3
$24/40
29 O.D. Approx.
24±3
38±3
15°±3
35°±3
285±5
50±3
15-16 I.D.
15-18 O.D.
250±5
35±3
$24/40
32±3

FIG. 3.—Types of Traps.

Solvents

4. (*a*) *For Use with Glass Still.*—When a glass still is to be used, 5 per cent of the solvent shall distill at a temperature between 194 F and 212 F; and 90 per cent shall distill below 410 F. Nonaromatic solvents are desirable when they are capable of dissolving or effectively dispersing the materials to be tested. They dissolve only infinitesimal quantities of water (less than 0.02 ml per 100 ml).

(*b*) *For Use with Metal Still.*—With a metal still and ring burner, a solvent may be used in which 98 per cent of the solvent distills at a temperature between 248 F and 482 F. Suitable adjustment of the position of the ring burner minimizes the bumping or frothing that may occur when the initial boiling point of the solvent is higher than that of water. The metal still is most commonly used in laboratories testing products derived from coal, and where a "light oil" distillate of the specified volatility, and possessing adequate solvent power, is normally available.

TABLE I.—RECOMMENDED SAMPLE SIZE AND APPARATUS.[a]

Material	Water Content, per cent	Size of Test Portion	Trap Size, ml	Still	Solvent (see Section)
Crude Petroleum and Petroleum Products	0 to 10	100 ml	10	glass	4(*a*)
	10 to 25	100 ml	25	glass	4(*a*)
	25 to 50	50 ml	25	glass	4(*a*)
Asphaltic Materials from Petroleum	0 to 10	100 ml	10	glass	4(*a*) or (*c*)
	10 to 25	100 ml	25	glass	4(*a*) or (*c*)
Asphalt Emulsion	0 to 25	100 g	25	glass or metal	4(*c*)
	25 to 50	50 g	25	glass or metal	4(*c*)
Bituminous Materials from Coal	0 to 10	100 ml	10	metal	4(*b*)
	10 to 25	100 ml	25	metal	4(*b*)

[a] It is permissible to use a 10-ml trap for samples containing more than 10 per cent of water, if the size of the test portion is suitably reduced. In case of such reduction, the quantity of water collected in the trap should not be less than 5 ml.

(*c*) *For Use with Either Glass or Metal Still.*—An effective solvent for tarry or asphaltic materials is a mixture of approximately 20 per cent benzene and 80 per cent xylene. This solvent may be used either in the glass or in the metal still. Aromatic solvents should be as dry as possible, since if even partly saturated with water, they may cause "plus" errors in the results (100 ml of benzene contains almost 0.1 ml of water when saturated at 90 F).

Sample

5. (*a*) Make sure that the test portion is thoroughly representative of the sample. Shake or stir the latter vigorously and, if still uncertain of its homogeneity, make determinations on two test portions, one poured from the container in the conventional manner and the other withdrawn from the bottom. Whenever possible, make sure that the sample is thoroughly representative of the bulk quantity of material from which it is drawn.

(*b*) The size of the test portion and the trap are dictated by the amount of water contained in the sample. Recommended sample sizes are given in Table I. When the sample is measured by volume, use a 100-ml graduated cylinder, and measure to the nearest 0.2 ml. When measured by weight, measure the sample to the nearest 0.1 g directly into the still.

Procedure

6. (*a*) Transfer to the still the required amount of sample, measured in accord-

ance with Table I, and add 100 ml of the solvent, taking care to avoid any loss of material. The type of distillation vessel is not an essential feature of the method, but a glass flask has been generally used for petroleum products, and a metal still for paving materials and tars, while both have been used in testing bituminous emulsions. When the material is measured by volume, pour as much of the sample as possible into the still or flask, then rinse the graduated cylinder with a 50-ml portion of solvent, followed by two successive 25-ml portions. Drain the cylinder as completely as possible after each rinsing.

(*b*) Connect the trap to the still and the condenser to the trap; make all connections vapor- and liquid-tight. When using the metal still, insert a gasket of heavy paper, moistened with solvent, between the flange and the lid, before attaching the clamp. When using the apparatus shown in Fig. 1 of the Supplement, adjust the condenser so that its tip will be submerged to a depth of about 1 mm below the surface of the liquid in the trap after distillation conditions have been established, and place the tip adjacent to the vapor-reflux tube. This arrangement minimizes a tendency for fine droplets of water to flow back to the still on the surface of the stream of reflux liquid. If glass-to-glass connections are used, it is desirable to lubricate lightly with Silicone lubricant.

(*c*) Insert a loose cotton plug in the top of the condenser tube to prevent condensation of atmospheric moisture in the tube. Any other device or scheme which accomplishes the same purpose and does not exert any back pressure, is permissible.

(*d*) Apply heat to the still or flask, and adjust the rate of boiling so that condensed distillate is discharged from the condenser at a rate of 2.5 to 6 ml per min. This corresponds approximately to a rate of 2 to 5 drops per sec. The use of "boiling stones" to promote even ebullition is often desirable. When using the ring burner with the metal still, place it about 3 in. above the bottom of the still at the beginning of the distillation and, without boil-over of contents, lower it gradually as the distillation proceeds until the burner is 25 to 50 mm below the bottom of the still.

(*e*) Continue the distillation at the specified rate until no water is visible on any part of the apparatus except at the bottom of the trap. This operation usually requires less than an hour. If there is a persistent ring of water in the condenser tube, remove it by increasing the rate of distillation for a few minutes.

NOTE 3.—Inability to remove water by this procedure is frequently due to dirt adhering to the inner surface of the condenser tube. An initial cleaning with chromic acid will normally eliminate this difficulty. A condenser, once clean, should remain clean.

Calculations

7. (*a*) *Petroleum and Bituminous Products.*—Calculate the water content of the sample (except lubricating grease and bituminous emulsions) as follows:

$$\text{Water, per cent by volume} = \frac{100\,A}{S}$$

where:

A = volume of water, in milliliters, and

S = volume of sample, in milliliters.

(*b*) *Bituminous Emulsions.*—Calculate the water content of the sample as follows:

$$\text{Water, per cent by weight} = \frac{100\,B}{W}$$

where:

B = volume of water collected, in milliliters, (assume this to be the weight of water in grams), and

W = weight of sample, in grams.

Precision

8. Results should not differ from the mean by more than the following amounts:

Water Content, per cent	Repeatability	Reproducibility
Petroleum Products and Bitumen:		
0 to 1	0.05	0.1
1 to 25	0.1	0.2
Asphalt Emulsions:		
0 to 1	0.05	0.1
1 to 25	0.1	0.2
25 to 50	0.2	0.4

SUPPLEMENT

APPARATUS

A1. *Glass Flask*, round-bottomed, short-necked, having a nominal capacity of 500 ml. Figures 1 and 2 show recommended tubulatures for (*1*) cork stopper connection, or (*2*) standard tapered glass connection.

A2. *Metal Still*, having an approximate capacity of 1000 ml. It may be constructed of any suitable metal; but copper is recommended for the vessel, and copper or brass for the lid. Dimensions and details of construction are given in Fig. 1.

A3. *Condenser*, Liebig straight type with a jacket not less than 400 mm long, and with an inner tube having an outside diameter of 9.5 to 12.7 mm. Figures 1 and 2 show characteristic details of construction of suitable condensers.

A4. *Traps*, of well-annealed glass, calibrated at four or more points by filling from a standard buret having a calibrated capacity equal to that of the trap, and conforming to the following requirements:

(*a*) *10-ml Capacity Traps*, graduated in 0.1-ml divisions from 0 to 1 ml, and 0.2-ml divisions from 1 to 10 ml. The error of the indicated capacity shall not exceed 0.05 ml from 0 to 1 ml, and 0.1 ml from 1 to 10 ml. Dimensions and details of construction are shown in Fig. 3.

(*b*) *25-ml Capacity Traps*, graduated from 0 to 1 ml in 0.1-ml divisions and from 1 to 25 ml in 0.2-ml divisions. The error of the indicated capacity shall not exceed one half the value of the adjacent graduated division. Dimensions and other details of construction are given in Fig. 3.

(*c*) *Ungraduated Trap with Stopcock.*—An alternate design, sometimes useful in testing samples of unpredictable water content, has a stopcock at the bottom. Such a trap may, in other respects, conform to the requirements of the 25-ml capacity trap, or it may be ungraduated. The volume of water can be measured by discharging it into an accurately graduated auxiliary cylinder of suitable dimensions.

A5. *Types of Traps.*—Details of size and design of several traps are indicated in Fig. 3. All of these conform to the mandatory requirements of this method.

(*a*) The simple trap involving cork-stopper connections and lacking a supplementary tube for reflux of condensed liquid must be used with a condenser having a 30 deg tip; accurate positioning of the condenser tip is important.

(*b*) The inclusion of a supplementary cross-over tube eliminates the necessity for the fragile condenser tip and the precise positioning of the latter. Traps with the supplementary tube can be made for use with cork stoppers, and are also suitable for construction with glass-to-glass joints.

APPENDIX VI

PROPOSED METHOD FOR POLAROGRAPHIC DETERMINATION OF TETRAETHYLLEAD IN GASOLINE[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method is intended for the polarographic determination of tetraethyllead in gasoline and in other volatile distillates.

Outline of Method

2. A gasoline sample is refluxed with hydrochloric acid, converting the lead present to lead chloride. Known quantities of cadmium chloride and gelatin are added to the acid extract in a 250-ml volumetric flask. After dilution to the mark, the lead content of the solution is determined polarographically.

Apparatus

3. (*a*) *Polarograph.*—Any polarograph, whether recording or nonrecording, may be adapted for this determination.

(*b*) *Extraction Apparatus.*—As described in ASTM Method D 526, Test for Tetraethyllead in Gasoline.[3]

(*c*) *Electrolysis Assembly.*—The electrolysis assembly shown in Fig. 1, consists of the following component parts:

(*1*) *Sample Cell.*[4]—The cell shown in Fig. 1 has been found satisfactory (Note 1). It is designed to enable an operator to change samples without having to assemble and dismantle the apparatus. A scratch mark on the cell indicates the volume of sample solution taken for analysis—about 10 ml.

NOTE 1.—Any other cell that will perform similarly may be used.

(*2*) *Anode.*—The anode is constructed by fusing a piece of No. 22 B & S gage silver wire at least 3 in. long to the top of a piece of anode silver 1.25 cm long, about 0.64 cm wide, and about 0.05 cm thick.

(*3*) *Cathode.*—A piece of marine barometer tubing approximately 6 to 7 cm in length, with a bore of about 0.04 mm, is connected by means of a small piece of Tygon tubing to a stand tube 75 cm in length. The stand tube is tapered at the bottom to approximately the outer diameter of the capillary tube, which is 6 to 7 mm. A side arm 5 cm from the bottom of the stand tube is connected to a leveling bulb containing mercury by means of about 2.5 ft of Tygon tubing. The capillary passes through a hole in the rubber stopper covering the cell, and its height is so adjusted that the tip of the capillary is $\frac{1}{4}$-in. below the surface of the solution in the cell. Inasmuch as the volume of liquid in the cell will always be approximately 10 ml, the position of the capillary, once set, will not require further adjustment. Electrical

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952.

[3] 1949 Book of ASTM Standards, Part 5.

[4] Obtainable from Fisher Scientific Co., Pittsburgh, Pa.

contact between the mercury in the reservoir and the polarograph is made with the usual platinum wire, sealed in a piece of narrow bore glass tubing partially filled with mercury and with a copper wire dipping into the mercury.

(*d*) *Nitrogen Bubbler System.*—A tank of nitrogen is fitted with suitable pressure regulators and needle valves to control gas flow to a few bubbles per second. Nitrogen from the tank flows through a fritted glass bubbler partially filled with water, and then through rubber tubing to a glass inlet tube passing through a rubber stopper large enough to close the sample cup.

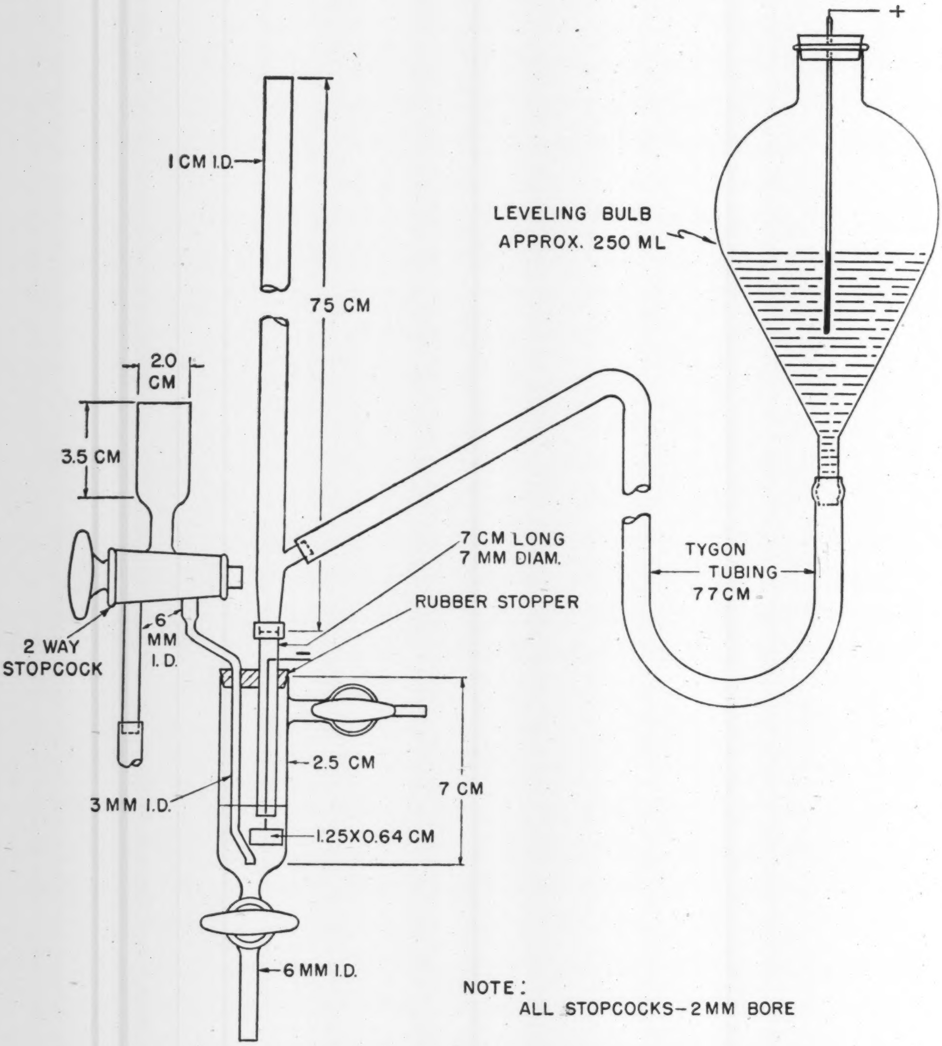
+
1 CM I.D.
75 CM
LEVELING BULB
APPROX. 250 ML
2.0 CM
3.5 CM
7 CM LONG
7 MM DIAM.
RUBBER STOPPER
TYGON
TUBING
77 CM
2 WAY
STOPCOCK
6 MM I. D.
2.5 CM
7 CM
3 MM I.D.
1.25X0.64 CM
6 MM I.D.
NOTE:
ALL STOPCOCKS-2 MM BORE

FIG. 1.—Electrolysis Assembly.

Reagents

4. Unless otherwise indicated, it is intended that all reagents conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

(*a*) *Gelatin Solution.*—Add 0.5 g of gelatin to 100 ml of warm distilled water. Warm the mixture on a steam plate until the gelatin is dissolved. Cool, and add 1 ml of toluene. Prepare a fresh solution weekly.

(*b*) *Hydrochloric Acid, Concentrated,* (*sp gr 1.19*).

(*c*) *Standard Lead Solution.*—Transfer 3.197 g of lead nitrate to a liter flask, dissolve the salt in lead-free distilled water and dilute to the mark.

NOTE 2.—Check the lead content on 50 ml of this standard solution by ASTM Method D 526, starting with Section 5 (*b*). 25 ml of this solution contains an amount of lead equivalent to that which is present in 50 ml of a gasoline at 15.6 C having a tetraethyllead content of 3.58 ml per gal.

(*d*) *Cadmium Chloride Solution.*—Dissolve 2.13 ± 0.01 g of cadmium chloride ($CdCl_2 \cdot 2\frac{1}{2}\ H_2O$) in lead-free distilled water, and dilute to 1 liter in a volumetric flask. The solution contains about 0.9 mg of cadmium per milliliter.

(*e*) *Mercury*, triple distilled.

(*f*) *Nitrogen*, oxygen-free tank nitrogen.

(*g*) *Lead-Free Heavy Distillate.*—A straight-run petroleum distillate, of low bromine number, with approximately 10 per cent distilling at 400 F and 90 per cent at 460 F.

(*h*) *Isooctane.*

Standardization

5. Extract 50 ml of *iso*octane as described in Section 6(*a*). Add 25 ml of the standard lead solution, 25 ml of the cadmium chloride solution, and 2 ml of gelatin solution. Dilute the solution to 250 ml with distilled water, and shake well to mix.

(*b*) Treat this standard sample as described in Section 6(*c*) to (*f*), inclusive.

NOTE 3.—This standardization is run each day at the start of a set of determinations. By its use, a regular calibration curve is unnecessary. This technique is justified, on the basis that in most methods frequent standardization runs are made to check the calibration curve anyhow.

Procedure

6. (*a*) Measure the temperature of the sample to the nearest 1.0 F. Using a pipet, transfer the volume of sample indicated in the following table to the extractor through the thistle tube:

Tetraethyllead Content, ml per gal	Volume of Sample, ml	Volume of Heavy Distillate, ml
0 to 2........	100	none
2 to 4........	50	50
4 to 6........	25	75

(*b*) Add the amount of heavy distillate shown in the above table (Note 4), and then add 50 ml of concentrated hydrochloric acid. Reflux the acid and gasoline for 30 min. Use the full heat of the heater until boiling has begun (usually 0.5 to 1 min) and then reduce the heat by regulating the rheostat so that there is at no time a steady stream of condensate from the condenser. After the 30-min reflux period, turn off the heat, allow the sample to cool a few minutes, and drain the acid layer into a 250-ml volumetric flask. Then add 50 ml of distilled water, and reflux the water and gasoline for 5 min, using the full heat of the heater Drain the water into the 250-ml flask; and repeat the extraction.

NOTE 4.—With highly volatile gasolines, omission of the distillate may lead to results which are low by 0.05 to 0.10 ml of tetraethyllead per gal.

(*c*) Pipet 2 ml of the gelatin solution and 25 ml of the standard cadmium solution to the extracts in the 250-ml flask. Dilute to the mark with distilled water, and shake well to mix.

(*d*) Pour about 10 ml of the sample solution into the sample cup. To rinse the cell, run the solution into the electrolysis cell and then out again through the lower stopcock. Rinse the cell again in a similar manner. Then run the sample solution into the cell to the 10-ml mark. Any excess solution in the sample cup is run to waste by turning the sample-cup stopcock in the appropriate direction. If necessary, adjust the height of solution in the cell to coincide with the 10-ml mark on the cell. Stopper the sample cup with the rubber stopper bearing the nitrogen inlet tube, and allow nitrogen to flow through the solution in the cell for 5 min with 3 to 4 bubbles per sec as the approximate flow rate. Turn off the nitrogen, and close all stopcocks that are still open.

(*e*) Connect the mercury cathode and silver anode to the polarograph. Make the following settings on the polarograph:

(*1*) Turn on power and battery switches.

(*2*) Set the initial potential at −0.2 v, and the spanning potential to 1.5 v if a recording polarograph is used. If another type of instrument is utilized, it should be so adjusted that the distance between the lead and cadmium curves is sufficient for their accurate wave height measurement.

(*3*) Set the sensitivity of the polarograph so that the polarogram covers about 80 to 85 per cent of the recorder chart or meter scale when the standard solution described in Section 5 is in the cell.

NOTE 5.—Once set for the standard, the sensitivity should not be changed during the series of determinations being made.

(*4*) Set the polarograph for the desired damping, and so adjust the instrument that, with the initial potential of −0.2 v, the recorder device is about 0.5 to 1.0 cm from the right edge of the recorder paper.

(*f*) To be certain that the diffusion current is constant, set the polarograph so that, with the initial potential at −0.2 v, a straight line is traced by the recorder pen for 2 cm. Start the polarograph to trace out a polarogram. When the current due to the lead begins to increase sharply, measure the drop time for five drops of mercury to fall from the cathode. This should require between 10 and 20 sec. If the drop time is out of this range, move the mercury leveling bulb up or down to obtain the desired drop rate, and rerun the polarogram. Check the drop time at the start of a series of runs, and it should not be necesssary to check it again during these runs.

(*g*) Measure the wave heights of the lead and the cadmium curves graphically,[5] or in any other convenient way. Record the ratio of the lead to cadmium wave heights.

NOTE 6.—If a nonrecording instrument is used, follow the above procedure up to and including Paragraph (*c*). Then connect the mercury cathode and silver anode to the polarograph and, after standardizing the polarograph, apply a potential of −0.8 v and measure the resulting diffusion current. Do the same thing for potentials of −0.53 and −0.3 v, respectively. The lead wave height is the difference between the currents at −0.3 and −0.53 v. The cadmium wave height is the difference between the currents at −0.53 and −0.80 v. Record the ratio of the lead wave height to the cadmium wave height.

(*h*) Prior to running the next sample, open the nitrogen outlet stopcock and the sample cup stopcock and run the solution in the cell into a waste beaker. Rinse the cell with the next sample, as described in Paragraph (*c*), and repeat the procedure.

Calculations

7. (*a*) *Calibration Factor*.—The wave-height ratio of the lead and cadmium

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[5] See "Polarographic Analysis," E. H. Sargent & Co., Chicago, Ill. (1941).

polarograms for the standard sample in Section 5, $\frac{\text{Pb}}{\text{Cd}}$, is equal to that which would be obtained if a sample having 3.58 ml of tetraethyllead per gal were determined by this method. Therefore:

$$F = \frac{C_{st}}{A_{st}}$$

where:

F = calibration factor,

C_{st} = concentration of standard in ml of tetraethyllead per gallon. (In this procedure, it is 3.58. Other laboratories may desire to use a standard of a different concentration), and

A_{st} = ratio of the wave heights, $\frac{\text{Pb}}{\text{Cd}}$ for the standard.

(*b*) Calculate the tetraethyllead content at temperature, t, as follows:

Tetraethyllead, ml per gal at temperature t

$$= \frac{FA}{2}, \text{for 100-ml samples,}$$
$$= FA, \text{ for 50-ml samples, and}$$
$$= 2\,FA, \text{ for 25-ml samples}$$

where:

F = calibration factor, and

A = ratio of the polarogram wave heights, $\frac{\text{Pb}}{\text{Cd}}$, for the sample.

(*c*) Calculate the tetraethyllead content at 60 F, as follows:

Tetraethyllead, ml per gal at 60 F

$$= C\,(1 + 0.0006\,(t - 60))$$

where:

C = ml of tetraethyllead per gal at observed temperature, and

t = observed temperature of gasoline when sampled, in degrees fahrenheit.

(See Supplement on p. 370.)

SUPPLEMENT

TABLE I.—SUMMARY OF RESULTS OF COOPERATIVE TESTS.

Results of Cooperative Tests with the Proposed Polarographic Method and ASTM Method D 526 for Tetraethyllead, Based on Work Done by Research Division III, Section F.

	Sample No. 1				Sample No. 2				Sample No. 3				Sample No. 4				Sample No. 5				Sample No. 6			
	ASTM D 526		Polarographic		ASTM D 526		Polarographic		ASTM D 526		Polarographic		ASTM D 526		Polarographic		ASTM D 526		Polarographic		ASTM D 526		Polarographic	
	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average	Ml TEL per Gal	Average
Laboratory A	0.00 0.00	0.00	0.00 0.00	0.00	0.07 0.07	0.07	0.09 0.10	0.10	1.51 1.53	1.52	1.57 1.52	1.54	3.08 3.10	3.09	3.10 3.06	3.08	4.59 4.45 4.39 4.37	4.45	4.50 4.56	4.53	2.83 2.79 2.79 2.72	2.78	2.76 2.75	2.76
Laboratory B	0.00 0.00	0.00	0.00 0.00	0.00	0.11 0.09	0.10	0.11 0.11	0.11	1.56 1.51	1.54	1.51 1.51	1.51	3.11 3.06	3.08	3.13 3.08	3.10	4.54 4.63	4.58	4.63 4.59	4.61	2.90 2.92	2.91	2.93 2.91	2.92
Laboratory C	0.00 0.00	0.00	0.00 0.00	0.00	0.13 0.12	0.12	0.12 0.13	0.12	1.53 1.51	1.52	1.54 1.53	1.54	3.04 3.06	3.05	3.06 3.09	3.08	4.65 4.63	4.64	4.64 4.59	4.62	2.89 2.90	2.90	2.93 2.91	2.92
Laboratory D	<0.02 <0.02	<0.02	None None	None	0.13 0.14	0.14	0.11 0.10	0.10	1.58 1.58	1.58	1.52 1.53	1.52	3.16 3.12 2.86 2.84	3.00	3.12 3.15	3.14	4.58 4.69	4.64	4.53 4.64	4.58	2.89 2.87	2.88	2.82 2.82	2.82
Laboratory E	0.00 0.00	0.00	0.00 0.00	0.00	0.12 0.12	0.12	0.11 0.11	0.11	1.56 1.53	1.54	1.54 1.52	1.53	3.10 3.07	3.08	3.16 3.19	3.18	4.50 4.52	4.51	4.72 4.66	4.69	2.92 2.90	2.91	2.91 2.90	2.90
Laboratory F	None None	None	None None	None	0.13 0.12	0.12	0.11 0.11	0.11	1.49 1.52	1.50	1.54 1.53	1.54	3.10 3.08	3.09	3.07 3.09 3.09	3.08	4.63 4.60	4.62	4.63 4.56 4.60	4.60	2.87 2.88	2.88	2.86 2.87	2.86
Laboratory G	0.01 0.01	0.01			0.11 0.12	0.12			1.54 1.54	1.54			3.11 3.12	3.12			4.59 4.60	4.60			2.87 2.87	2.87		
Laboratory H	0.00 0.00	0.00			0.10 0.11	0.10			1.50 1.53 1.52	1.52			3.09 3.07	3.08			4.60 4.55	4.58			2.75 2.79 2.81	2.78		
Laboratory I	0.00 0.00	0.00	0.00 0.00	0.00*	0.11 0.10	0.10	0.12 0.12	0.12*	1.49 1.45	1.47	1.38 1.34	1.36*	3.04 3.03 3.02 2.97	3.02	3.12 2.91 2.91	2.98*	4.50 4.45	4.48	4.32 4.22 4.20	4.25*	2.88 2.84 2.83 2.81	2.84	3.07 3.01 2.98	3.02*
Laboratory J	None None	None	None None	None	0.08 0.07	0.08	0.10 0.11	0.10	1.52 1.53	1.52	1.50 1.51	1.50	3.14 3.13	3.14	3.06 3.07	3.06	4.58 4.58	4.58	4.63 4.63	4.63	2.89 2.87	2.88	2.90 2.88	2.89
									Summary of Statistical Treatment of Data															
Theoretical Values			0.00				0.11				1.53				3.08				4.57				2.88	
$\bar{x}$ Mean or Average Values		0.00		0.00		0.11		0.11		1.52		1.53		3.06		3.10		4.56		4.61		2.85		2.87
Maximum Spread between Determinations		—		—		0.07		0.04		0.13		0.07		0.32		0.13		0.32		0.22		0.20		0.18

* These Values were Omitted in the Statistical Treatment of the Results Reported.

APPENDIX VII

PROPOSED METHOD OF TEST FOR TENSILE STRENGTH OF PARAFFIN WAX[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) This method of test describes a procedure for obtaining an empirical measure of the tensile strength of paraffin wax having a ductility not exceeding approximately $\frac{1}{8}$-in. elongation at the specified temperature and relative humidity of the test, and having ASTM melting points (ASTM Method D 87),[3] in the range of approximately 120 to 150 F. This method may also be used for other types of petroleum waxes, compounded waxes, or waxes with ASTM melting points in excess of 150 F, provided they are of the same order of ductility, and provided they do not exhibit excessive contraction on cooling the cast specimen.

NOTE 1.—For waxes which exhibit excessive contraction, special casting techniques beyond the scope of this test method are required.

(*b*) Many purchasers and manufacturers have found tensile strength of the type obtained by this method to be useful as a guide in controlling the over-all quality of paraffin wax. Because the conditions of preparing the sample and applying the load to the test specimen are not necessarily identical with service conditions, the tensile strength values obtained by this method generally cannot be assumed as indicative of the performance which could be expected in service, although some laboratories have observed a correlation in certain applications.

Description of Term

2. *Tensile strength* is the longitudinal stress (ultimate pure tensile load) required to break a representative specimen of specified shape and cross-sectional area.

Outline of Method

3. (*a*) A set of six specimens per test sample are cast with $\frac{1}{4}$-sq-in. cross-section mold of specified shape, and aged for 2 hr in a room held at 73 F and a 50 per cent relative humidity. Tensile strength is measured by applying a load of 20 lb per sec, and is reported in pounds per square inch by converting the breaking load of a $\frac{1}{4}$-sq-in. cross-section specimen to a 1-sq-in. basis.

(*b*) Such factors as manner and speed of testing, shape and cross-section of specimen, manner of specimen preparation, conditioning of the specimen, surface condition of the specimen, and the presence of strains in the specimen, all influence the magnitude and precision of test results and, therefore, must be carefully controlled.

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, June, 1952.

[3] 1949 Book of ASTM Standards, Part 5.

Apparatus

4. (*a*) *Testing Machine.*—Any universal testing machine may be used, provided it is accurate to 1 per cent of the lowest load to be applied, and provided that the load is applied at a constant, uniform rate. The resultant direction of the applied tensile load should coincide with the longitudinal center line of the test specimen, and shall permit alignment to be adjusted rapidly and accurately. The machine shall be of such a design that it can be readily calibrated with standard dead weights over the entire range of loads to be applied.

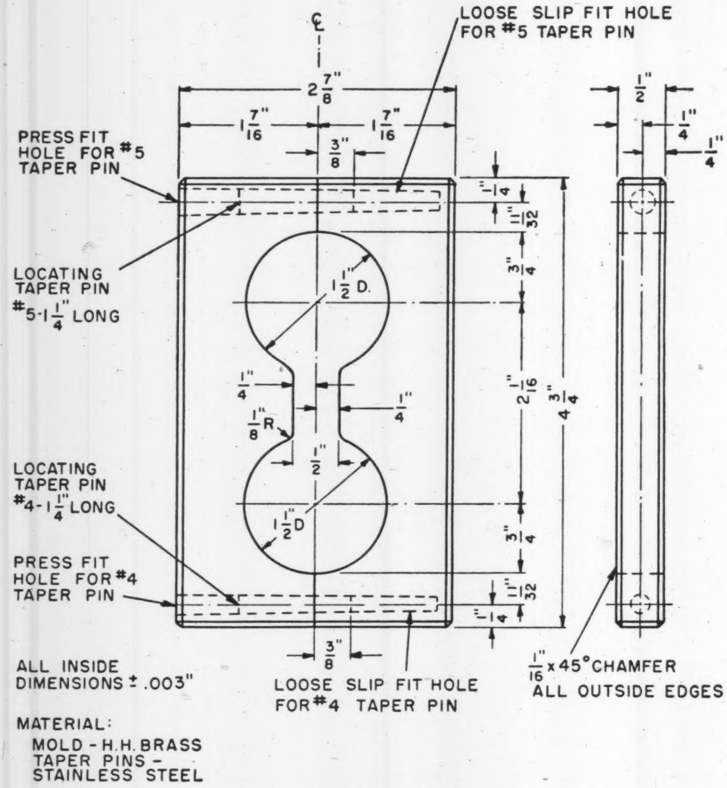
LOOSE SLIP FIT HOLE FOR #5 TAPER PIN
℄
2 7/8"
1 7/16"
1 7/16"
3/8"
1/2"
1/4"
1/4"
PRESS FIT HOLE FOR #5 TAPER PIN
1/4"
1/32"
LOCATING TAPER PIN #5-1 1/4" LONG
1 1/2" D.
3/4"
1/4"
1/4"
1/8" R.
2 1/16"
4 3/4"
1/2"
LOCATING TAPER PIN #4-1 1/4" LONG
1 1/2" D
3/4"
PRESS FIT HOLE FOR #4 TAPER PIN
1/32"
1/4"
3/8"
ALL INSIDE DIMENSIONS ± .003"
LOOSE SLIP FIT HOLE FOR #4 TAPER PIN
1/16" x 45° CHAMFER ALL OUTSIDE EDGES
MATERIAL:
MOLD - H.H. BRASS
TAPER PINS - STAINLESS STEEL

FIG. 1.—Test Specimen Mold.

(*b*) *Test Specimen Molds and Cover Plates,* constructed as described in the Supplement, Section A1, and as shown in Fig. 1. The mold has a $\frac{1}{4}$-sq-in. cross-section.

NOTE 2.—The mold described in the Supplement is commonly known as the Perkins Mold. Two additional mold designs, the Modified Dow and the Mellon Institute Modified Mold, are currently being studied by Section I, of Technical Committee M. Decision regarding the most satisfactory mold design will be made before publication of this method as Tentative. Drawings and information on the latter two molds may be obtained from the chairman, Mr. J. W. Padgett, Moore and Munger, 33 Rector St., New York 6, N. Y.

(*c*) *Specimen Grips,* universally self-aligning type, for holding the specimen in the machine. A suitable type is described in the Supplement, Section A2, and shown in Fig. 2.

(*d*) *Cooling Rack, and Base Plate,* constructed as described in the Supplement, Section A3, and as shown in Fig. 3.

(*e*) *Water Bath* capable of maintaining a temperature of 73 ± 0.5 F, for conditioning the test specimens, shall be entirely covered, and shall be equipped with a floating grid to assure complete submergence of the test specimens. Dimensions of the bath are not critical; but, preferably, the material used in its construction should be of stainless steel.

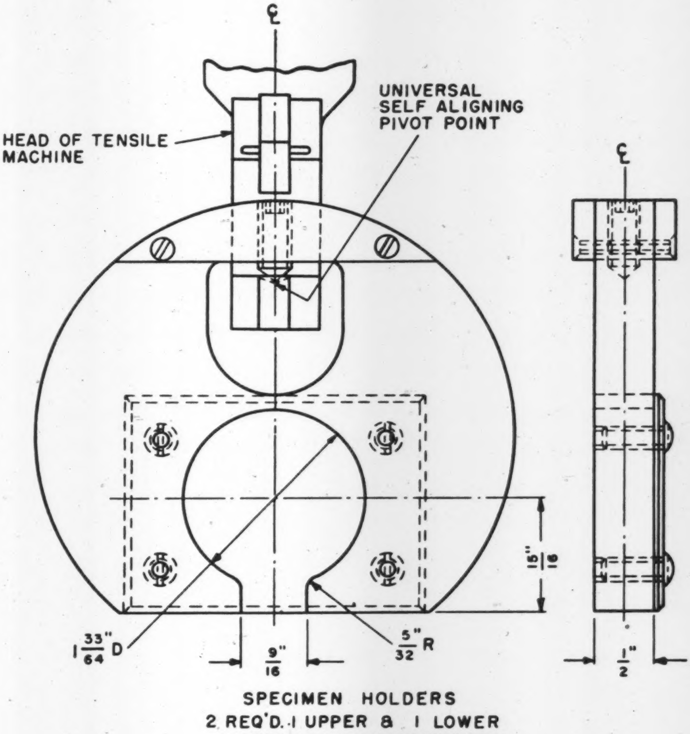

FIG. 2.—Test Specimen Grips.

(*f*) *Oven,* capable of maintaining a temperature of 212 ± 5 F.

(*g*) *Thermometers.*—For the water bath, the ASTM Precision Thermometer having a range of 25 to 85 F, graduated in 0.2 F intervals, and conforming to the requirements for Thermometer 63F as prescribed in ASTM Standard Specifications E 1,[3] shall be used. For wax stirring, the ASTM Partial Immersion Thermometer having a range of 0 to 302 F, graduated in 2 F intervals, and conforming to the requirements for Thermometer 1F as prescribed in ASTM Specifications E 1, shall be used.

(*h*) *Test Room,* maintained at a temperature of 73 ± 1 F, and at a relative humidity of 50 ± 5 per cent.

NOTE 3.—Tests may be made for routine control or investigation purposes at other temperatures and humidities, provided that the temperature does not vary more than ±1 F, and that the relative humidity does not vary more than ±5 per cent during the entire test. Results, however, should not be considered comparable to those obtained in this test.

Calibration and Inspection of Apparatus

5. (*a*) *Calibration.*—Carefully check the tension testing machine for alignment. Calibrate it periodically, at least once every three months, with certified standard dead weights. Use no less than four dead-weight combinations for calibration; and select them to cover the operating range in equal increments.

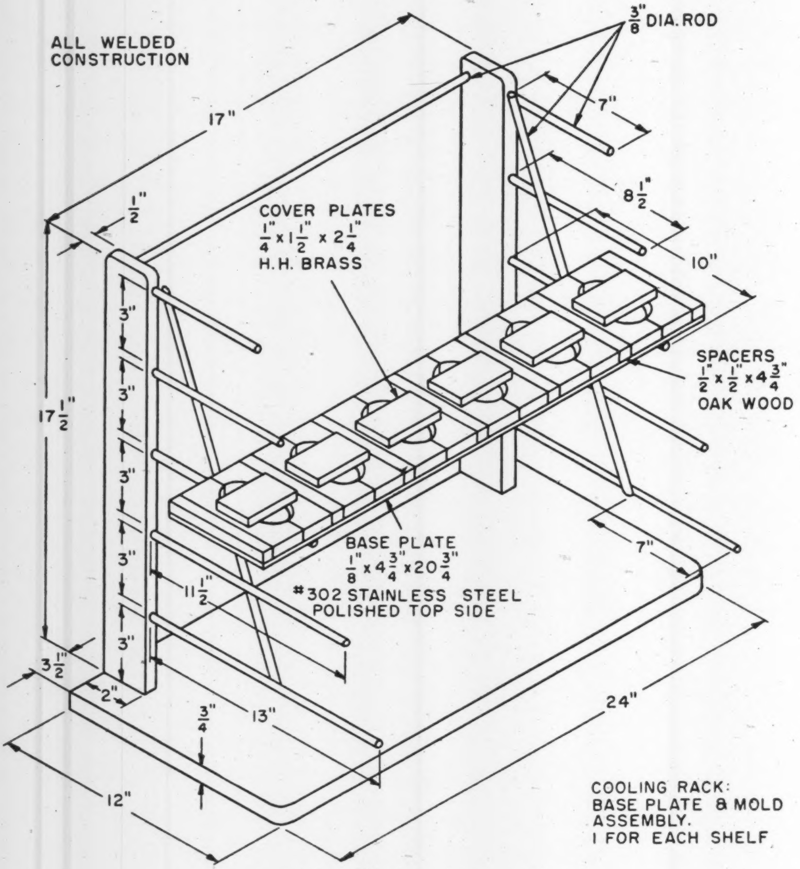
ALL WELDED CONSTRUCTION
$\frac{3}{8}$" DIA. ROD
17"
7"
$8\frac{1}{2}$"
10"
$\frac{1}{2}$"
COVER PLATES
$\frac{1}{4}$" x $1\frac{1}{2}$" x $2\frac{1}{4}$"
H. H. BRASS
3"
3"
3"
3"
3"
$17\frac{1}{2}$"
SPACERS
$\frac{1}{2}$" x $\frac{1}{2}$" x $4\frac{3}{4}$"
OAK WOOD
BASE PLATE
$\frac{1}{8}$" x $4\frac{3}{4}$" x $20\frac{3}{4}$"
#302 STAINLESS STEEL
POLISHED TOP SIDE
7"
$11\frac{1}{2}$"
$3\frac{1}{2}$"
2"
$\frac{3}{4}$"
13"
24"
12"
COOLING RACK:
BASE PLATE & MOLD
ASSEMBLY.
1 FOR EACH SHELF

FIG. 3.—Cooling Rack and Mold Supports.

(*b*) *Standardization.*—In addition to calibration, the apparatus should be standardized periodically, at least once a month, with standard waxes[4] having tensile strengths in the normal operating range of the test. Standard samples should be prepared and retained by individual laboratories, and should be renewed at least once a year.

(*c*) *Mold Inspection.*—Check the molds, cover plates, and base plates periodically to determine the absence of dents, nicks, and scratches which could cause points of stress concentration in the test specimen.

(*d*) *Glassware Cleaning.*—Glassware should be set aside and used only for this test. It is imperative that it be cleaned properly to avoid errors due to contamination. To clean glassware, heat gently over a Bunsen burner to a temperature slightly above 212 F, and then wipe clean with a lint-free cloth.

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[4] Standard samples of high- and low-tensile strength waxes are being retained at present by Section I on Strength Tests, of Technical Committee M, ASTM Committee D-2. Limited quantities of these standards are available on request to the Chairman, Mr. J. W. Padgett, Moore and Munger, 33 Rector St., New York 6, N. Y.

Preparation of Molds

6. (*a*) Carefully scrape any adhering wax from the molds, and wipe them clean with a lint-free cloth. Film-coat the insides of the brass molds and brass cover plates, and top of the stainless steel base plate with mold-release compound.[5] Apply only a very thin film by wiping with a cloth or pad saturated with, but not containing an excess of, mold release compound, and then wipe with a clean, dry, lint-free cloth.

(*b*) Assemble the molds and wood spacers on the base plate, and the base plate on the cooling rack as described in the Supplement, Section A3, and as shown in Fig. 3. Place the brass cover plates over the center of the molds so that the length of each plate is perpendicular to the length of the mold (Fig. 3). Place the cooling rack and mold assembly in an area free from vibration.

(*c*) Place a set of prepared molds on the cooling rack for at least 1 hr before use.

Preparation of Test Specimens

7. (*a*) Select an amount of sample sufficient to cast six specimens (approximately 200 g). Obtain a different portion of the sample for each set of six specimens. If the sample is 1 lb or less, melt the entire amount; if greater than 1 lb, take extra precautions to obtain a representative sample in accordance with applicable quartering techniques.

(*b*) Transfer that portion of the wax sample to be tested to a clean glass beaker (Section 5(*d*)) and cover with a clean watch glass; melt each six-specimen portion in a separate beaker. Place the beaker for 2 hr in an oven regulated to a temperature of 212 ± 5 F.

(*c*) After 2 hr in the oven, the wax sample will be completely melted, and the temperature of the bulk of the wax will be at approximately 180 F. At this time, remove the beaker from the oven and decant all but approximately 20 ml into a second clean glass beaker. Heat gently to 230 ± 2 F (Note 4) with very mild stirring on a hot plate, using an asbestos pad. Use the ASTM Partial Immersion Thermometer 1F for stirring, and adjust the hot plate to heat the wax at the rate of 10 ± 2 F per min.

NOTE 4.—If required, filter the wax at this temperature through coarse filter paper placed in a 125-mm diameter glass funnel with a 10-mm stem. Discard the first 20 ml. Reheat sample to 230 F, using the prescribed rate.

(*d*) With very mild stirring, carefully adjust the sample temperature to 230 ± 2 F and pour rapidly, filling as full as possible without overflowing, into six previously conditioned molds placed in the cooling rack (see Section 6(*c*)). Do not disturb the cooling rack and mold assembly in any manner whatsoever after the sample has been poured. Use the thermometer as a pouring aid. Record the ambient temperature and relative humidity at the time of pouring. After 2 hr ± 10 min, carefully remove the wax specimens from the molds and place them in the water bath, maintained at 73 ± 0.5 F for 15 min, before breaking in the testing machine. Immerse the specimens completely in the water by placing them under the floating grid (Section 4(*e*)).

Procedure

8. (*a*) Seat the specimen firmly and uniformly in the holder attached to the heads of the testine machine, so that the resultant direction of the applied tensile load coincides with the longitudinal center line of the test specimen. Immediately the specimen is mounted, load the machine at a rate of 20 lb per sec for the standard $\frac{1}{4}$-sq-in. cross-section mold. Record the machine load at the moment

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[5] Dow Corning Mold-Release Compound No. 7, or any other equivalent compound.

the two portions of the test specimen are separated, and the nature of the fracture.

(*b*) Immediately repeat the tensile measurement on the remaining five specimens for the given test. Record the average ambient temperature and relative humidity at the time the tensile measurements are made.

(*c*) Calculate the mean of the results of the six tensile measurements in pounds, as read from the machine. Discard the result for any specimen whose value differs from this mean by more than 9 lb. Record the mean of the results for the remaining specimens as the value for the sample. If results of more than two specimens are discarded from any set of six, discard all six results of that set.

Report

9. (*a*) Report the mean load value for each set of test specimens, calculated for a 1-sq-in. cross-section, to the nearest 1 lb per sq in.

(*b*) Report the predominating type of fracture as *clean* or *irregular*. Report the average distance of the fracture from the center of each of the six specimens to the nearest ⅛ in.

(*c*) Report the room temperature and relative humidity at the time of pouring the test specimens and at the time the tensile measurement is made, if they differ from 73 F and 50 per cent relative humidity. Results obtained under such conditions shall not be considered as conforming to the requirements of this method.

Precision

10. The following criteria should be used for judging the acceptability of the mean of results of tests on sets of four to six test specimens:

(*a*) *Repeatability.*—The means of duplicate sets of results by the same operator should be considered suspect if they differ by more than the following amounts:

Range	Repeatability
150 to 450 psi..................	24 psi

(*b*) *Reproducibility.*—The means of pairs of sets of results obtained in different laboratories should be considered suspect if they differ by more than the following amounts:

Range	Reproducibility
150 to 450 psi..................	36 psi

SUPPLEMENT

APPARATUS

A1. *Specimen Molds and Cover Plates*, for casting the test specimens, constructed of half-hard brass in accordance with the requirements shown in Fig. 1. A 1½ by 2¼ by ¼-in. half-hard brass cover plate shall be supplied with each mold.

A2. *Specimen Grips*, universally self-aligning type, for fastening the test specimen to the tension test machine. A suitable mount with universal self-aligning pivot arrangement between the specimen holders and machine heads is shown in Fig. 2.

A3. *Cooling Rack and Mold Supports:*

(*a*) *Rack*, of metal rod, constructed as shown in Fig. 3.

(*b*) *Base Plate*, for supporting the molds in the rack, constructed of ⅛-in. No. 302 stainless steel as specified in ASTM Specifications A 167 for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip.[6] The width of the base plate shall be equal to the length of the mold, and the length of the base plate shall be equal to six times the width of the mold, plus 3½ in.

(*c*) *Spacers for Molds*, of oak wood, ½ in. square, and equal in length to the length of the mold, for uniformly separating the molds on the base plate.

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[6] 1949 Book of ASTM Standards, Part 1.

APPENDIX VIII

PROPOSED MANOMETRIC METHOD WITH NULL PRESSURE TRANSMITTER FOR VAPOR PRESSURE TEST OF PETROLEUM PRODUCTS[1]

This method is a proposed addition to ASTM Method D 323, Test for Vapor Pressure of Petroleum Products (Reid Method), and is published as information only. Comments are solicited, and should be addressed to the American Society for Testing Materials at 1916 Race Street, Philadelphia 3, Pa.

Apparatus

A1. (*a*) *Null-Pressure Transmitter*, consisting of two gas chambers separated by a flexible, impervious membrane. The lower chamber shall contain a suitable coupling for attachment to the air chamber of the vapor pressure bomb. The volume of the lower chamber minus the volume of the displacement tube shall not be greater than the volume of the Bourdon tube of the gages now specified. The upper chamber shall be connected with an air-pressuring device and null indicator. The transmitter shall be capable of sensing a pressure differential between lower and upper chambers of 0.02 psi or less. It must be sufficiently stable so that observations in sequence can be reproduced within 0.02 psi without readjustment. The apparatus[2] shown in Fig. 3, with protective cap for adjustment nuts, conforms to these requirements; it should be constructed of stainless steel to resist water corrosion.

(*b*) *Contact Indicator*, consisting of three $\frac{1}{25}$-w neon lamps, each in series with a 200,000-ohm resistor. The lamps shall be mounted at convenient locations next to the manometer scale and near points of frequent measurement, so that an indicator lamp and the corresponding mercury level can be observed simultaneously. The electrical circuit is shown in Fig. 2.

NOTE 1.—Any other indicating or sensing device may be employed, provided that the sensitivity and stability prescribed in Section A2 (*b*) can be attained with its use.

(*c*) *Manometer*, range 0 to 50 in., graduated in pounds and tenths of pounds.[3]

(*d*) *Assembly*, as shown in Fig. 2, with test chamber and null-pressure transmitter, fitted with identical quick-connect couplings.[4] The test chamber shall have a capacity approximately that of the Reid bomb and sample chamber (Note 2). The neon light indicator, with lights at appropriate points beside the manometer for easy observation, provides an electrically safe method of sensing unbalance of the transmitter shown in Fig. 1.

NOTE 2.—The test chamber may be independent of the test line as shown in Fig. 4, or may be permanently connected to it by appropriate valve-arrangements.

Preparation of Apparatus

A2. (*a*) *Transmitter Adjustment.*—Make daily checks on the adjustment of the transmitter. Attach the transmitter and air hose to the test chamber. Bring the chamber to a pressure of 7 to 9 psi, as indicated on the mercury manometer, and close the needle valve on the test chamber. Transfer the air hose connection to its transmitter connection, and attach the electrical contact plug. With the vent valve closed, open the air valve and apply a balancing pressure to the transmitter (Note 3) equal to that in the test chamber. To adjust the contact of the transmitter shown in Fig. 1, release the lock nut on the Teflon plug and move the upper contact up or down; the null point is sensed by opening the vent valve very slightly to obtain a practically static balance (very slight flutter between over- and under-balance) as shown by blinking of the neon lamp.

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[1] This proposed addition to ASTM Method D 323 is under consideration by Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1952.

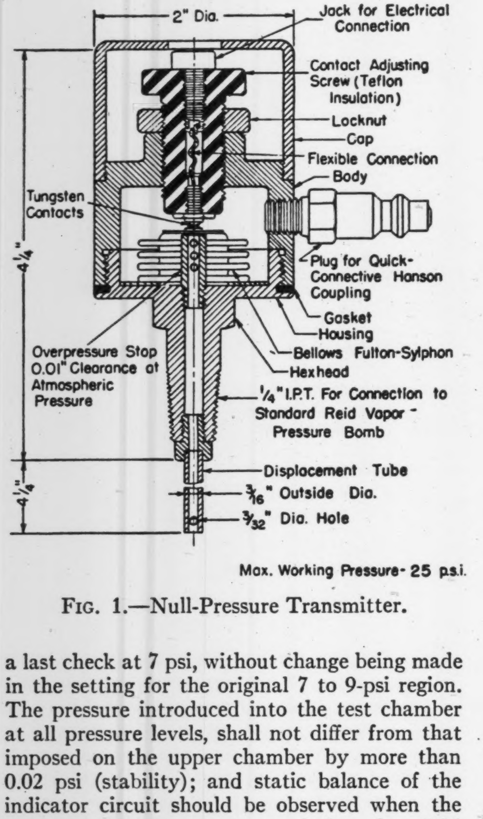
[2] Currently available from Precision Scientific Co., Chicago, Ill.

[3] Merriam manometer, Model A 203, meets these requirements.

[4] Available from Hansen Mfg. Co., 4031 W. 150th St., Cleveland, Ohio; Plug Series 3000, No. 12 (steel); Socket Series 3000, No. 3SB3 (brass).

NOTE 3.—Any time the contact point of the transmitter, Fig. 1, has been removed from the body, replace it by screwing in as far as necessary to make contact. This will avoid overpressuring and rupturing the bellows by a possible high pressure in the test chamber.

(*b*) *Sensitivity and Stability Test.*—With the transmitter contact adjusted and locked for balance in the 7 to 9-psi region, release the pressure in the test chamber and repressure at about 2 psi, then at about 16 psi, and then for a last check at 7 psi, without change being made in the setting for the original 7 to 9-psi region. The pressure introduced into the test chamber at all pressure levels, shall not differ from that imposed on the upper chamber by more than 0.02 psi (stability); and static balance of the indicator circuit should be observed when the movement on the manometer is less than 0.02 psi (sensitivity). After adjustment and test, the transmitter should indicate within 0.02 psi all pressures in the Reid bomb up to 24 psi.


2" Dia.
Jack for Electrical Connection
Contact Adjusting Screw (Teflon Insulation)
Locknut
Cap
Flexible Connection
Body
Tungsten Contacts
4¼"
Plug for Quick-Connective Hanson Coupling
Gasket
Housing
Overpressure Stop 0.01" Clearance at Atmospheric Pressure
Bellows Fulton-Sylphon
Hexhead
¼" I.P.T. For Connection to Standard Reid Vapor-Pressure Bomb
Displacement Tube
3/16" Outside Dia.
3/32" Dia. Hole
4¼"

Max. Working Pressure- 25 p.s.i.

FIG. 1.—Null-Pressure Transmitter.

NOTE 4.—If permanent connection between air supply and test chamber is made, it might be convenient to insert a U-tube mercury manometer across the two sides of the transmitter to observe any drift in the sensing element, instead of observing it on the test manometer.

(*c*) *Maintenance.*—The sensitivity of the transmitter may be affected by moisture and dirty or corroded contacts. To eliminate moisture, remove the quick-connect plug and blow air in through a small tube. At times the transmitter may need to be opened and the contact points cleaned, although very little cleaning of tungsten contact points is ordinarily required. To remove sample contamination from the inner part of the bellows, disconnect the displacement tube from the bottom of the transmitter and blow air into the bellows by means of a small tube.

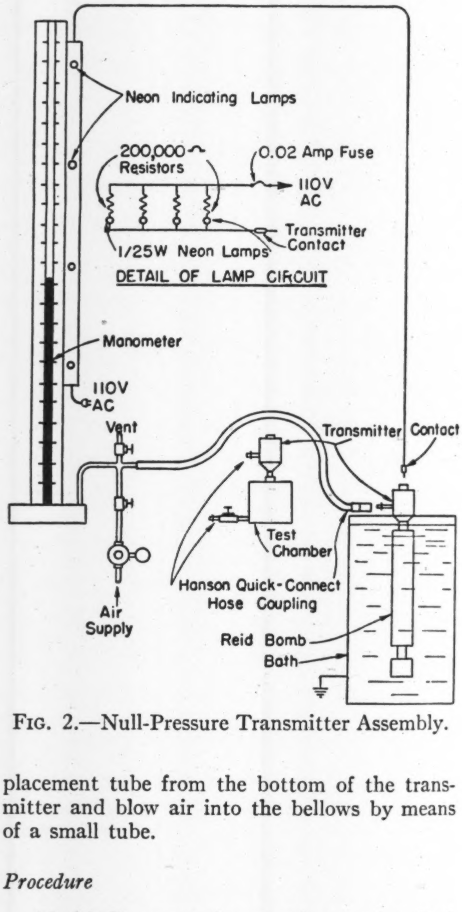

Neon Indicating Lamps
200,000 ~ Resistors
0.02 Amp Fuse
110V AC
Transmitter Contact
1/25W Neon Lamps
DETAIL OF LAMP CIRCUIT
Manometer
110V AC
Vent
Transmitter
Contact
Test Chamber
Hanson Quick-Connect Hose Coupling
Air Supply
Reid Bomb
Bath

FIG. 2.—Null-Pressure Transmitter Assembly.

Procedure

A3. (*a*) Carry out the procedure as described in Sections 4, 5, 6, and 9 of the Reid Method D 323, substituting the null-pressure transmitter for the gage. With the neon light indicator connected to the transmitter and the vent valve closed, open the air valve to apply a pressure nearly balancing that in the Reid bomb, to obtain an approximate reading on the manometer. To obtain final adjustment of the null point, open the vent valve very slightly (with the air valve partially open) until a state of static balance is indicated by a blinking of the neon indicator lamp.

(*b*) Read the pressure on the mercury manometer at this null point as the Reid vapor pressure within the bomb.

Precision

A4. The following criteria should be used for judging the acceptability of results when testing identical samples with the null-pressure transmitter and with the Bourdon gage in the range of 3 to 16 psi.

(*a*) *Repeatability.*—Duplicate results by the same operator should not differ by more than the following amounts:

	Repeatability
Null-pressure transmitter.........	0.3
Bourdon gage....................	0.3

(*b*) *Reproducibility.*—The average of two results in each of two laboratories should not differ by more than the following amounts:

	Reproducibility
Null-pressure transmitter.........	0.5
Bourdon gage....................	0.5

APPENDIX IX

PROPOSED METHOD OF TEST FOR OIL CONTENT OF PETROLEUM WAXES[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. This method describes a test procedure for the determination of oil in petroleum waxes having a melting point of 105 F or higher, and containing not more than 15 per cent of oil.[2]

NOTE.—This method is essentially the same as ASTM Method D 721 - 51 T, Tentative Method of Test for Oil Content of Paraffin Wax,[3] but it has been modified by a stirring operation in order to extend the procedure to microcrystalline waxes, which may dissolve with difficulty in methylethylketone.[4]

Outline of Method

2. The sample is dissolved in methylethylketone, the solution cooled to −25 F to precipitate the wax, and filtered. The oil content of the filtrate is determined by evaporating the methylethylketone and weighing the residue.

Apparatus

3. The following apparatus[5] is required:

(*a*) *Filter Stick and Assembly*, consisting of a 10-mm diameter medium-porosity sintered glass filter stick, provided with an air pressure inlet tube and delivery nozzle. It is provided with a ground-glass joint to fit a 25 by 170-mm test tube. The dimensions for a suitable filtration assembly are shown in Fig. 1.[6]

NOTE.—A metallic filter stick may be employed if desired. A filter stick made of stainless steel and having a ½-in. disk of medium porosity has been found to be satisfactory.[7] The metallic apparatus is inserted into a 25 by 150-mm test tube and held in place by means of a cork.

(*b*) *Cooling Bath*, consisting of an insulated box with 1-in. holes in the center to accommodate any desired number of test tubes. The bath may be filled with a suitable medium such as kerosine, and may be cooled by circulating a refrigerant through coils, or by using solid carbon dioxide. A suitable cooling bath to accommodate three test tubes is shown in Fig. 2.[6]

(*c*) *Dropper Pipet*, provided with a rubber bulb, and calibrated to deliver 1 ± 0.05 g of molten wax.

(*d*) *Transfer Pipet*, calibrated to deliver 15 ± 0.06 ml.

(*e*) *Air Pressure Regulator*, designed to supply air to the filtration assembly (Section 6(*e*)) at the volume and pressure required to give an even flow of filtrate.

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1951.

[2] This method is being used by some laboratories for products of lower melting point and higher oil content.

[3] 1951 Supplement to Book of ASTM Standards, Part 5.

[4] The oil content values obtained on microcrystalline waxes must be considered only arbitrary values where "oil" is defined by the conditions of this test. These values will generally not agree with those obtained by other methods employing different solvents or conditions.

[5] This apparatus may be obtained from Kopp Scientific Laboratory Equipment, Inc., 405 East 62nd St., New York 21, N. Y.

[6] These illustrations of the apparatus are identical with those appearing in Method D 721 - 51 T, 1951 Supplement to Book of ASTM Standards, Part 5.

[7] A suitable metal filter stick with designated porosity G may be obtained from the Micro Metallic Corp., 193 Bradford Street, Brooklyn, N. Y.

Either the conventional pressure-reducing valve or a mercury bubbler-type regulator has been found satisfactory. The latter type, illustrated in Fig. 3,[6] consists of a 250-ml glass cylinder and a T-tube held in the cylinder by means of a rubber stopper grooved at the sides to permit the escape of excess air. The volume and pressure of the air supplied to the filtration assembly is regulated to a depth to which the T-tube is immersed in mercury at the bottom of the cylinder. Absorbent cotton placed in the space above the mercury prevents the loss of mercury by spattering. The air pressure regulator is connected to the filter stick and assembly by means of rubber tubing.

(*f*) *Thermometers.*—Oil in Wax Thermometers having the range of −35 to +70 F and conforming to the proposed specifications appearing in the Supplement to Method D 721 − 51 T.[3]

(*g*) *Weighing Bottles*, conical in shape and glass-stoppered, having a capacity of 15 ml.

(*h*) *Evaporation Assembly*, consisting of an evaporating cabinet and connections, essentially as illustrated in Fig. 4,[6] and capable of maintaining a temperature of 95 ± 2 F around the evaporation flasks. Construct the jets with an inside diameter of 4 ± 0.2 mm for delivering a stream of clean, dry air vertically downward into the weighing bottle. Support each jet so that the tip is 15 ± 5 mm above the surface of the liquid at the start of the evaporation. Supply air at the rate of 2 to 3 liters per min per jet, purified by passage through a tube of 1-cm bore packed loosely to a height of 20 cm with absorbent cotton. Periodically check the cleanliness of the air by evaporating 4 ml of methylethylketone by the procedure specified in Section 6(*e*). When the residue does not exceed 0.1 mg, the evaporation equipment is operating satisfactorily.

(*i*) *Analytical Balance*, capable of reproducing weights to 0.1 mg. The sensitivity should be adjusted so that 0.1 mg will deflect the pointer one half division on the pointer scale.

(*j*) *Wire Stirrer.*—A piece of stiff iron or nichrome wire of about No. 20 B & S gage, 250 mm long. A 10-mm diameter loop is formed at each end, and the loop at the bottom end is bent so that the plane of the loop is perpendicular to the wire.

Solvent

4. *Methylethylketone*, conforming to ASTM Specifications D 740, for Methyl Ethyl Ketone,[8] and having a refractive index at 68 F of 1.378 ± 0.002. The residue remaining after the evaporation of 4 ml by the procedure specified in Section 6(*e*) must not exceed 0.1 mg.

Sample

5. If the sample of wax is 2 lb or less, obtain a representative portion by melting the entire sample and stirring thoroughly. For samples over 2 lb, exercise special care to insure obtaining a truly representative portion, bearing in mind that the oil may not be distributed uniformly throughout the sample, and that mechanical operations may express some of the oil.

Procedure

6. (*a*) Melt a representative portion of the sample in a beaker, using a water bath or oven maintained at 160 to 210 F. As soon as the wax is completely melted, thoroughly mix by stirring. Preheat the dropper pipet in order to prevent the solidification of wax in the tip, and withdraw a 1-g portion of the sample as soon as possible after the wax has melted. Hold the pipet in a vertical position, and carefully transfer its contents into a clean, dry test tube previously weighed to the nearest 1 mg (Note 1). Swirl the

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[8] 1949 Book of ASTM Standards, Part 4.

test tube so as to coat the bottom evenly with wax. This permits more rapid solution later. Allow the test tube to cool, and weigh to the nearest 1 mg.

NOTE 1.—The weight of a test tube which is cleaned by means of solvents will not vary to a significant extent. Therefore, a tare weight may be obtained and used repeatedly.

(*b*) Pipet 15 ml of methylethylketone into the test tube and place the latter just up to the level of its contents in a hot water or steam bath. Heat the solvent - wax mixture, stirring up and down with the wire stirrer, until a homogeneous solution is obtained. Exercise care to avoid loss of solvent by prolonged boiling.

NOTE 2.—Very high-melting microcrystalline wax samples may not form clear solutions. Stir until the undissolved material is well dispersed as a fine cloud.

Plunge the test tube into an 800-ml beaker of ice water and continue to stir until the contents are cold. Remove the stirrer. Remove the test tube from the ice bath, wipe dry on the outside with a cloth, and weigh to the nearest 0.1 g.

NOTE 3.—During this operation the loss of solvent through vaporization should be less than 1 per cent. The weight of the solvent is, therefore, practically a constant, and, after a few samples are weighed, this weight, approximately 11.9 g, can be used as a constant factor.

(*c*) Place the test tube containing the wax - solvent slurry in the cooling bath, which is maintained at −30 ± 2 F. During this chilling operation it is important that stirring by means of the thermometer be almost continuous, in order to maintain a slurry of uniform consistency as the wax precipitates. Do not allow the wax to set up on the walls of the cooling vessel nor permit any lumps of wax crystals to form. Continue stirring until the temperature reaches −25 ± 0.5 F.

(*d*) Immerse in the mixture the clean, dry filter stick, which has previously been cooled by placing it in a test tube and holding at −30 ± 2 F in the cooling bath for a minimum of 10 min. Seat the ground-glass joint of the filter so as to make an air-tight seal. Place an unstoppered weighing bottle, previously weighed together with the glass stopper to the nearest 0.1 mg, under the delivery nozzle of the filtration assembly.

NOTE 4.—Take every precaution to insure the accuracy of the weight of the stoppered weighing bottle. Prior to determining this weight, rinse the clean, dry, weighing bottle and stopper with methylethylketone, wipe dry on the outside with a cloth, and place in the evaporation assembly to dry for about 5 min. Then remove the weighing bottle and stopper, place near the balance, and allow to stand for 10 min prior to weighing. Stopper the bottle during this cooling period. Once the weighing bottle and stopper have been dried in the evaporation assembly, lift only with forceps. Take care to remove and replace the glass stopper with a light touch.

(*e*) Apply air pressure to the filtration assembly, and immediately collect about 4 ml of filtrate in the weighing bottle. Release the air pressure to permit the liquid to drain back slowly from the delivery nozzle. Remove the weighing bottle immediately, and stopper and weigh to the nearest 10 mg without waiting for it to come to room temperature. Unstopper the weighing bottle and place it under one of the jets in the evaporation assembly maintained at 95 ± 2 F, with the air jet centered inside the neck, and the tip 15 ± 5 mm above the surface of the liquid. After the solvent has evaporated, which usually takes less than 30 min, remove the bottle, stopper, and place near the balance. Allow to stand for 10 min and weigh to the nearest 0.1 mg. Repeat the evaporation procedure, using a 5-min evaporation period instead of 30 min, until the loss between successive weighings is not over 0.2 mg.

Calculation

7. Calculate the amount of oil in the wax as follows, and if the result is negative report as zero.

Oil in Wax, per cent by weight

$$= \frac{100\,AC}{BD} - 0.15$$

where:

A = weight of oil residue, in grams,
B = weight of wax sample, in grams,
C = weight of solvent, in grams, obtained by subtracting weight of test tube plus wax sample (Section 6(*a*)) from weight of test tube and contents (Section 6(*b*)), and
D = weight of solvent evaporated, in grams, obtained by subtracting weight of weighing bottle plus oil residue from weight of weighing bottle plus filtrate (Section 6(*e*)).

0.15 = average factor correcting for the solubility of wax in the solvent at −25 F.

Precision

8. Results should not differ from the mean by more than the following amounts:

	Repeatability	**Reproducibility**
Oil in Wax, per cent	One Operator and Apparatus	Different Operators and Apparatus
Under 1.........	0.1	0.2
1 and over.......	0.2	0.4

REPORT OF COMMITTEE D-3

ON

GASEOUS FUELS*

A meeting of Committee D-3 On Gaseous Fuels and of its Advisory Committee was held in Atlantic City on June 19, 1951. Three of its subcommittees also met on the previous day, while a fourth met in St. Louis on October 16, 1951.

Election of officers for the ensuing two-year term resulted in the election of the following:

Chairman, A. W. Gauger.

Vice-Chairman, F. E. Vandaveer.

Secretary, K. R. Knapp.

Advisory Committee: S. W. Burdick, G. C. Putnam, E. F. Schmidt, and Martin Shepherd.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Test for Specific Gravity of Gaseous Fuels (D 1070 - 49 T) be approved by the Society for adoption as standard, revised as appended hereto.[1] This recommendation has been submitted to letter ballot of the committee and approved unanimously.

AMERICAN STANDARDS

Recommendation was made by Committee D-3 that the Standard Method of Test for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter (D 900 - 48) be submitted by the Society to the American Standards Association for adoption as American Standard. Acting on this recommendation, such submission was made by letter dated February 25, 1952. Subsequent to adoption as ASTM Standard, at the 1952 Annual Meeting, the Method of Test for Specific Gravity (D 1070) will also be submitted to the ASA for approval as American Standard.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Collection of Gaseous Samples (F. E. Vandaveer, chairman).—The first meeting of this subcommittee since the appointment of its present chairman was held in Atlantic City in June, 1951. Following the decision reached at this meeting, a completely revised Proposed Tentative Method of Sampling Manufactured Gas was prepared by Messrs. J. F. Anthes and Raymond Sheridan of Brooklyn Gas Co. This revised method was forwarded to all members of the subcommittee on December 4, 1951. Replies to date have been very favorable. Further action on this proposed method will be taken at the next meeting of the subcommittee and Committee D-3.[2]

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman).—The status of the Tentative Methods for Measurement of Gaseous Fuel Samples (D 1071 - 49 T) was discussed at the October, 1951, meeting of the subcommittee. It was felt that these methods should remain in the tentative status until some variations in the procedure for testing laboratory wet test meters under their provisions could be reconciled with those of other existing methods. As a result of the discussion of steps to be taken toward adoption of a satisfactory common procedure, it was proposed that several laboratories be asked to conduct a series of comparative calibrations, and a single procedure be prepared and submitted to the subcommittee. Those present at the meeting agreed with the chairman that $\frac{1}{10}$-cu ft bottles should be calibrated "to deliver" and not "to contain."

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 5.

[2] See Editorial Note, p. 386.

Subcommittee IV on Determination of Specific Gravity and Density of Gaseous Fuels (E. F. Schmidt, chairman).—The Tentative Methods of Test for Specific Gravity of Gaseous Fuels (D 1070 - 49 T) were revised by this subcommittee as appended[1] to this report. These revisions consist of editorial changes, in addition to necessary modifications and additions to more clearly cover the various procedures set forth. The subcommittee also recommended to Committee D-3 the adoption as standard of the tentative methods as revised.

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (L. T. Bissey, chairman, formerly H. Hakewell).—At its June, 1951, meeting, the subcommittee reached decision to proceed with the preparation of a revised referee method for total sulfur determination to be published as information. It was also agreed to collect information on other methods for sulfur determination from organizations having such data available.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (S. W. Burdick, chairman).—Principal attention has been devoted to endeavoring to find other suitable methods to supplement the Tentative Method of Test for Water Vapor Content of Gaseous Fuels by Measurement of Dew-Point Temperature (D 1142 - 50 T). These include the wet and dry bulb method, the calcium hydride method, and the Karl Fischer method, all of which have been considered.

Subcommittee VII on Complete Analysis of Chemical Composition of Gaseous Fuels (Martin Shepherd, chairman).—Several conferences have resulted in agreement on procedures for the mass spectrometric analysis of carburetted water gas and related gaseous fuels. A third revision is being prepared for submission as a tentative method. A volumetric-chemical method is also in preparation. Study is also being devoted to methods for the analysis of heavy hydrocarbons.

This report has been submitted to letter ballot of the committee, which consists of 38 members; 29 members returned their ballot, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. W. GAUGER,
Chairman.

K. R. KNAPP,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-3 presented to the Society through the Administrative Committee on Standards a proposed Tentative Method of Sampling Manufactured Gas. This recommendation was accepted by the Standards Committee on December 12, 1952, and the new tentative method appears in the 1952 Book of ASTM Standards, Part 5, bearing the designation D 1247 - 52 T.

REPORT OF COMMITTEE D-4
ON
ROAD AND PAVING MATERIALS*

Committee D-4 on Road and Paving Materials has held two meetings during the past year: in Atlantic City, N. J., on June 21, 1951, and in Cleveland, Ohio, on March 6, 1952.

In the death of Roy W. Crum, Director of the Highway Research Board, National Research Council, on May 13, 1951, Committee D-4 lost a highly honored former member and past chairman who for many years was a very active committee member and contributed much to the advancement of our knowledge of testing and specifications for highway materials. Mr. Crum's membership in the Society dated from 1911. He was chairman of Committee D-4 from 1928 to 1930. At the time of his decease he had just completed 40 years of continuous affiliation with the ASTM and long-time service on several of its committees. The record of Roy W. Crum is one of sustained helpfulness and outstanding accomplishment in his chosen field of engineering research.

At its meeting on June 21, 1951, the committee recognized the long service of Shreve Clark, a member of Committee D-4 since 1931, and committee chairman from 1944 to 1946, by electing him to honorary membership. Mr. Clark, as Engineer of Tests of the Virginia Department of Highways, had represented that organization in ASTM since 1920, and completed many years of service as the engineer responsible for materials used by that highway department.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee D-4 presented two groups of recommendations to the Society through the Administrative Committee on Standards. The following were accepted for publication on September 12, 1951:

Tentative Method of Test for:

Specific Gravity of Compressed Bituminous Mixtures (D 1188 – 51 T),[1]

Tentative Specifications for:

Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (D 692 – 51 T),[1]

Revision of Tentative Specifications for:

Fine Aggregate for Sheet Asphalt and Bituminous Concrete Pavements (D 1073 – 51 T),[1]

Tentative Revision of Standard Specifications for:

Granite Block for Pavements (D 59 – 39),[1] and

Withdrawal of Standard Specifications for:

Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (D 692 – 49).[1]

Another group of recommendations for publication of tentatives and tentative revisions of standards was accepted by the Administrative Committee on Standards on February 15, 1952, as follows:

Tentative Method of:

Testing Concrete Joint Sealers (D 1191 – 52 T),

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1951 Supplement to Book of ASTM Standards, Part 3.

Test for Vacuum Distillation of Liquid and Semi-Solid Asphaltic Materials to Obtain a Residue of Specified Penetration (D 1189 - 52 T),

Tentative Specifications for:

Concrete Joint Sealer, Hot-Poured Elastic Type (D 1190 - 52 T),

Tentative Revision of Standard Method of:

Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements, and Soft Tar Pitches (D 70 - 27),

Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (D 71 - 27), and

Tentative Revision of Standard Specifications for:

Sodium Chloride (D 632 - 43).

These tentative methods, tentative specifications, and tentative revision of standard specifications will appear in the 1952 Book of ASTM Standards, Part 3. The tentative revisions of standard methods of test for specific gravity of bituminous materials, with some editorial modifications, are being recommended for adoption as standard as given later in this report.

TABLE I.

Size Number	Nominal Size	Amounts Finer than Each Laboratory Sieve (Square Openings), per cent by weight						
		2½ in.	2 in.	1½ in.	1 in.	¾ in.	½ in.	⅜ in.
3	2 in. to 1 in.	100	95 to 100	35 to 70	0 to 15	...	0 to 5	...
4	1½ in. to ¾ in.	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5

NEW TENTATIVES

Committee D-4 recommends that the proposed Tentative Specifications for Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 544 - 52 T), as appended to this report,[2] be accepted for publication. These proposed specifications emphasize performance requirements of joint filler materials rather than their composition and, when adopted as standard, are intended to replace existing standard specifications (D 544 - 49).

REVISIONS OF TENTATIVES

Tentative Specifications for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (**D 947 - 49 T**).[3]—Committee D-4 recommends a revision of these tentative specifications to provide for two additional sizes of coarse aggregate, which may be used in producing the specified mixtures, and to be more specific in defining permissible variations from an established job mix and applications of the tolerances in composition. The recommended changes are as follows:

Table I.—Add the sizes shown in the accompanying Table I.

Section 5.—Change to read as follows:

5. The mixture shall conform to one of the compositions by weight given in Table III. A job mixture shall be selected that comes within the specified limits and that is suitable for the traffic, climatic conditions, and specific gravities of the aggregates used. Any variation from the job mix formula in the grading of the aggregate, as shown by sieve analysis of materials in the plant bins, of more than ±5 per cent in the total passing the No. 8 (2380-micron) sieve, or ±2 per cent in the total passing the No. 200 (74-micron) sieve, or any variation from the job mix formula in the asphalt content as indicated by extraction tests of the finished mixture of more than ±0.3 per cent, shall be investigated, and the conditions causing such variation shall be corrected.

NOTE.—It is recognized that the extraction test is a generally accepted and approved method for determining the composition of a bituminous concrete mixture. However, due to the relatively wide difference in bitumen content of individual samples of bituminous material taken from the same batch, as shown by extraction tests, it is recommended that the extraction test results be used as an indication of the mix composition, and not as the sole basis for acceptance or rejection of the product.

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[2] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

[3] 1949 Book of ASTM Standards, Part 3.

Section 8.—Add paragraph (*f*), to read as follows:

(*f*) *Determination of Bitumen Content.*—Tentative Method of Test for Bitumen Content of Paving Mixtures by Centrifuge (ASTM Designation: D 1097).[4]

Tentative Specifications for Asphaltic Mixtures for Sheet Asphalt Pavements (**D 978 - 49 T**).[3]—Committee D-4 recommends revision of Section 5 of these specifications to accord with the proposed revision of Section 5 in Tentative Specifications D 947 - 49 T[3] and for similar reasons. The recommended changes are as follows:

Section 5.—Change to read as follows:

5. Binder course and surface course mixtures shall conform, respectively, to one of the compositions by weight given in Table III. For each course a job mixture shall be selected that comes within the specified limits and that is suitable for the traffic, climatic conditions, and specific gravities of the aggregates used. Any variation from a job mix formula in the grading of the aggregate, as shown by sieve analysis of materials in the plant bins, of more than ±5 per cent in the total passing the No. 8 (2380-micron) sieve, or ±2 per cent in the total passing the No. 200 (74-micron) sieve, or any variation from the job mix formula in the asphalt content as indicated by extraction tests of the finished mixture of more than ±0.3 per cent, shall be investigated, and the conditions causing such variation shall be corrected.

NOTE.—It is recognized that the extraction test is a generally accepted and approved method for determining the composition of a bituminous paving mixture. However, due to the relatively wide difference in bitumen content of individual samples of bituminous mixture taken from the same batch, as shown by extraction tests, it is recommended that the extraction test results be used as an indication of the mix composition, and not as the sole basis for acceptance or rejection of the product.

Section 8.—Add Paragraph (*f*), to read as follows:

(*f*) *Determination of Bitumen Content.*—Tentative Method of Test for Bitumen Content of Paving Mixtures by Centrifuge (ASTM Designation: D 1097).[4]

Tentative Specifications for Crushed Stone, Crushed Slag, and Gravel for Single Bituminous Surface Treatment (**D 1139 - 50 T**).[4]—As an editorial revision to state the objective of a single bituminous treatment more correctly, the committee recommends that the second sentence of Section 4 be changed to read as follows, by the deletion of words in brackets and the addition of the italicized words:

[The purpose of] a single surface treatment is [to place the aggregate] *a wearing surface of bituminous material and aggregate in which the aggregate is placed* uniformly over the bituminous material in a *single* layer [approximately one piece of aggregate in thickness], *the thickness of which approximates the nominal maximum size of the aggregate.*

Tentative Method of Tests for Compressive Strength of Bituminous Mixtures (**D 1074 - 49 T**).[3]—The committee recognizes that the size of specimen has an influence on the results of this compressive strength test, and recommends the following revision:

Section 4.—Change the first paragraph to read as follows, by the delection of the words and figures in brackets and the addition of the italicized words and figures:

4. Generally the test specimens shall be cylinders [4] *4.0* in. in diameter and [4] *4.0* ± 0.1 in. in height. *It is recognized that the size of test specimens has an influence on the results of the compressive strength test. Cylindrical* specimens of [other sizes] *dimensions other than 4.0 in.* may [however,] be used, *however*, provided:

Tentative Methods of Sampling Bituminous Materials (**D 140 - 49 T**).[3]—Committee D-4 joins with Committee D-8 on Bituminous Waterproofing and Roofing Materials in recommending that these tentative methods be revised.[5]

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[4] 1950 Supplement to Book of ASTM Standards, Part 3.

[5] The revised method was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 3.

The existing tentative has been extensively rearranged and reworded to provide a more logical sequence and improved clarity of meaning, at the same time inserting additional requirements which have been found desirable. The proposed method, as revised, is appended hereto.[5]

TENTATIVE REVISION OF STANDARD

Standard Specifications for Bituminous Mixing Plant Requirements (**D 995 – 51**).[3]—The committee believes that in many cases the required capacity of the bitumen bucket stated in Paragraph *3(c)* of the standard is excessive, particularly for producers of bituminous concrete paving mixtures who seldom prepare mixtures requiring more than 7.5 per cent of bitumen. The committee recommends, therefore, publication of a tentative revision of this standard, as follows:

Section 3(c).—Change the first sentence to read as follows by the addition of the italicized words and figures and the omission of the words and figures in brackets:

> (*c*) *Bitumen Bucket*.—If a bucket is used for weighing the bitumen, it shall have [sufficient] *a* capacity [to hold not] *at least 4.0 per cent greater than the maximum percentage of bitumen which the producer anticipates using per batch of mixture, but in no case shall the capacity of the bucket be* less than [15] *11.0* per cent of the rated capacity of the mixer.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Committee D-4 recommends approval of the following revisions of standards for immediate adoption, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that the recommendations may be referred to letter ballot of the Society:

Standard Definitions of Terms Relating to Materials for Roads and Pavements (**D 8 – 51**).[3]—Delete the terms "Liquid Asphalt," "Road Asphalt," and "Consistency," together with the corresponding definitions, from the standard. The first two are identified as trade terms only, not subject to definition, and therefore are not appropriately included in the standard definitions. A superior definition of "consistency" is included in Standard Definitions of Terms Relating to Rheological Properties of Matter (E 24 – 42).[3]

Standard Method of Test for Distillation of Tar Products Suitable for Road Treatment (**D 20 – 30**).[3]—A proposed revision of this standard method was published for information with the annual report of Committee D-4 last year. The important change in this revision was for the purpose of defining the shield for protection of the burner; otherwise, changes in wording were proposed to clarify the text and arrange the paragraphs in a more logical order. Further editorial modifications of the proposed revision have been approved, and immediate adoption as standard of the revised method of test, as appended hereto,[5] is recommended.

ADOPTION OF TENTATIVES AS STANDARD

Committee D-4 recommends that the following tentative methods of test be approved for reference to letter ballot of the Society for adoption as standard, without revision:

Tentative Method of Test for Bitumen (D 4 – 49 T), replacing Standard Method of Test for Determination of Bitumen (D 4 – 42), and

Tentative Method of Test for Resistance to Plastic Flow of Fine-Aggregate Bituminous Mixtures (D 1138 – 50 T).

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Method of Test for Penetration of Bituminous Materials (**D 5 – 49**).[3]—Committee D-4 recommends that the tentative revision of this standard, issued January, 1950, be approved for reference to letter ballot of the Society for adoption as standard. As a strictly editorial change, it is also recommended that the first sentence of Section 5(*c*) be revised to read as follows by the addition of the italicized words and the omission of those in brackets:

> (*c*) When desirable to vary the temperature, and in order to provide for a uniform method of reporting results when variations are made, the following combinations of temperature, time, and [weight] *load* are suggested:
> At 0 C. (32 F.)..... 200-g [weight] *load*, 60 sec
> At 46.1 C. (115 F.).. 50-g [weight *load*, 5 sec.

Standard Method of Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements, and Soft Tar Pitches (**D 70 – 27**),[3] and *Standard Method of Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments* (**D 71 – 27**).[3]—The committee recommends that tentative revisions of these standards, accepted by the Administrative Committee on Standards on February 15, 1952, with further revisions of an editorial nature, be approved for reference to letter ballot of the Society for adoption as standard. The additional changes are intended to improve the wording and describe the procedures more specifically, with no modification in characteristic features of the methods. The recommended standards are appended hereto.[6]

WITHDRAWAL OF STANDARD

In view of the recommendation for adoption as standard of the Tentative Method of Test for Bitumen (D 4 – 49 T), presented earlier in this report, Committee D-4 recommends that the Standard Method of Test for Determination of Bitumen (D 4 – 42) be withdrawn.

REAFFIRMATION OF STANDARDS

The committee recommends that the following nine standards, which have been published for six years or longer without revision, be reaffirmed:

Standard Method of Test for:

Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42),
Specific Gravity and Absorption of Fine Aggregate (C 128 – 42),
Sieve Analysis of Fine and Coarse Aggregates (C 136 – 46),
Abrasion of Rock by Use of the Deval Machine (D 2 – 33),
Toughness of Rock (D 3 – 18),
Ductility of Bituminous Materials (D 113 – 44),
Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 – 46),
Sieve Analysis of Mineral Filler (D 546 – 41), and

Standard Volume Correction Table for Tar and Coal Tar Pitch (D 633 – 44).

STANDARDS CONTINUED WITHOUT REVISION

Committee D-4 recommends that the following standards be continued as standard without revision. All of these standards have been reviewed by the subcommittees responsible for their development and revision, and found to be satisfactorily in accordance with present practice.

Standard Specifications for:

Materials for Cement Grout Filler for Brick and Stone Block Pavements (D 57 – 20),
Materials for Sand-Cement Bed for Brick and Block Pavements (D 58 – 27),
Granite Block for Pavements (D 59 – 39),
Coal-Tar Pitch for Stone Block Filler (D 112 – 30),
Recut Granite Block for Pavements (D 131 – 39),
Granite Block for Durax Pavements (D 132 – 39),
Asphalt Filler for Brick Pavements (D 241 – 43),
Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 – 39),
Cut-Back Asphalt (Rapid Curing Type) (D 597 – 46),
Cut-Back Asphalt (Medium Curing Type) (D 598 – 46), and
Sodium Chloride (D 632 – 43).

Standard Methods of:

Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 – 26),
Test for Softening Point of Tar Products (Cube-in-Water Method) (D 61 – 38),

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[6] The revisions were accepted by the Society and the standards in their revised form appear in the 1952 Book of ASTM Standards, Part 3.

Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 46),

Test for Proportion of Bitumen Soluble in Carbon Tetrachloride (D 165 - 42),

Test for Residue of Specified Penetration (D 243 - 36),

Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 - 44),

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 - 44), and

Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 - 44).

TENTATIVES CONTINUED WITHOUT REVISION

The subcommittees of Committee D-4 and the joint subcommittee of Committees D-4 and D-18 have reviewed existing tentative specifications and methods of test which have been published by the Society for two years or more without revision, and Committee D-4 recommends that the following be continued as tentative without revision:

Tentative Specifications for:

Materials for Stabilized Base Course (D 556 - 40 T), and Materials for Stabilized Surface Course (D 557 - 40 T).—The joint subcommittee of Committees D-4 and D-18, in cooperation with a committee of the American Association of State Highway Officials, has prepared a specification covering these materials which Committee D-4 proposes to offer as a revision of the two tentative specifications containing simpler and more direct requirements for suitable materials.

Asphalt Cement for Use in Pavement Construction (D 946 - 47 T).—These specifications should be retained as tentative while Subcommittee C-1 develops additional requirements to secure improved control of the properties and uniformity of asphalt cements.

Preformed Expansion Joint Filler for Concrete (Bituminous Type) (D 994 - 48 T).—Subcommittee D-3 of Committee D-4 is considering the desirability of revision of these specifications.

Tentative Methods of Test for:

Soft Particles in Coarse Aggregates (C 235 - 49 T).—This tentative method is under the joint jurisdiction of Committee D-4 and Committee C-9 on Concrete and Concrete Aggregates. Subcommittee B-12 is considering suggestions for revision of requirements.

Loss on Heating of Oil and Asphaltic Compounds (D 6 - 39 T).—This tentative method has been in extensive use for many years, and should be retained until an improved procedure is developed and adopted.

Moisture-Density Relations of Soils (D 698 - 42 T).—Committee D-18 on Soils for Engineering Purposes, which has joint jurisdiction with Committee D-4 on this tentative method, is considering revision of this method.

Soil-Bituminous Mixtures (D 915 - 47 T).—As indicated in recent annual reports of Committee D-4, further study of this procedure is desirable in respect to correlation with construction control and service performance of highway soils. The method is in use by a number of highway construction agencies, and it is expected that a subcommittee of Committee D-18, which has joint jurisdiction of this tentative with Committee D-4, will assemble appropriate data on the applicability and utility of the tentative method under practical conditions.

Shear Strength of Flexible Road Surfaces, Subgrades and Fills by the Burggraf Shear Apparatus (D 916 - 47 T).—The tentative method should be retained pending further development, as indicated in the 1950 Annual Report of Committee D-4.

Effect of Water on Cohesion of Compacted Bituminous Mixtures (D 1075 - 49 T).—Subcommittee B-2 and B-25 of Committee D-4 are cooperating in further development and standardization of procedures, considering various types of bituminous mixtures. These investigations may lead to revisions of the tentative method to extend the scope of its application and utility.

Bitumen Content of Paving Mixtures by Centrifuge (D 1097 - 50 T).—The Committee is considering minor revisions of this tentative method.

Tentative Revision of Standard:

Definitions of Terms Relating to Materials for Roads and Pavements (D 8 - 49).—The committee is considering further revision of the tentative definition for "tar" issued in June, 1949.

The recommendations appearing in this report have been approved by letter ballot of the committee, the results of which will be reported at the Annual Meeting.[7]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee B-1 on Asphalt Content (J. H. Swanberg, chairman), in developing the new Tentative Method of Test for Vacuum Distillation of Liquid and Semi-Solid Asphaltic Materials to Obtain a Residue of Specified Penetration (D 1189 - 52 T), the acceptance of which was mentioned earlier in this report, conducted an elaborate series of cooperative tests in which several methods of obtaining 100-penetration residue were compared. Fourteen samples of SC-3 road oil, varying in characteristics, were used in the series of tests in which seven laboratories participated. Selected data from these tests, immediately pertinent to the determination of 100-penetration residue, are presented in Appendix I.[8]

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[7] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee B-2 on Physical Tests for Compressed Bituminous Mixtures (L. F. Rader, chairman) is continuing its cooperation with the Triaxial Institute through a project group comprising subcommittee members who are also active in investigations conducted by the Triaxial Institute. The latter organization is engaged in fundamental studies, at present concentrating on methods for formation of specimens and the influence of compaction methods on the physical properties of compacted specimens. The subcommittee has held a number of meetings for the presentation and discussion of fundamental data bearing on the physical testing of bituminous mixtures, and is considering the standardization of additional procedures.

Subcommittee B-3 on Distillation Tests (H. P. Ferguson, chairman) plans to conduct a series of cooperative tests by the Standard Method of Test for Distillation of Tar Products, a revision of which is recommended in this report, for the purpose of obtaining data for preparation of a statement on reproducibility. This subcommittee is also reviewing critically the proposed revisions of the Standard Method of Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 46) which are also being considered by Committee D-2 on Petroleum Products and Lubricants.[9] The important feature of suggested revisions is to provide for the use of glass-to-glass connections.

Subcommittee B-7 on Viscosity and Float Tests (C. A. Benning, chairman) plans to conduct cooperative tests to obtain data on reproducibility of the Engler specific viscosity test, for which a proposed tentative method has been prepared.

Subcommittee B-12 on Structural Properties of Mineral Aggregates (Stanton Walker, chairman) is surveying the field of future activities for the subcommittee. Among the problems considered are the effect of aggregates on slipperiness of road surfaces, methods of measuring the angularity of fine and coarse aggregates, and thermal properties of aggregates.

Subcommittee B-16 on Setting Qualities of Bituminous Materials (A. B. Cornthwaite, chairman) is continuing its cooperative test program to develop a method to measure the curing properties of bituminous materials, with particular attention to rapid-curing and medium-curing cut-back materials. Results now available indicate the need for further standardization of apparatus and technique.

Subcommittee B-17 on Emulsion Tests (R. R. Thurston, chairman) has completed a test program to establish an acceptable procedure for determining the viscosity of emulsified asphalts at 122 F. A proposed tentative method will be offered to Committee D-4 for consideration at an early meeting.

Subcommittee B-19 on Accelerated Tests for Durability of Bituminous Materials (J. H. Goshorn, chairman) has reviewed a number of thin film oven and weathering tests and proposes to organize a cooperative testing program to study the thin film oven test.

Subcommittee B-25 on Effect of Water on Compressed Bituminous Mixtures (C.

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[8] See p. 396.

[9] See p. 358.

A. Carpenter, chairman) plans to undertake cooperative tests with a view to expanding the use of Tentative Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures (D 1075 - 49 T) to the evaluation of bituminous mixtures containing liquid binders. This subcommittee has conducted several series of tests in the development of the present tentative method, and plans to prepare a summary of these tests for publication.

Subcommittee B-26 on Effect of Water on Bituminous Coated Aggregates (C. M. Hewett, chairman) for the past several years has conducted cooperative tests designed to develop a procedure for measuring the adhesion of bituminous films to mineral aggregates and resistance of these films to "stripping." While this work has not resulted in recommendations for publication of a standardized test method, it has developed much valuable information on features of the usual "stripping" tests and their limitations. A summary report on the work has been prepared by Mr. J. C. Roediger, former chairman of the subcommittee, with the assistance of the present chairman and, in view of extensive interest in the subject by producers and consumers of highway materials, is appended to this report as Appendix II.[10]

Subcommittee D-3 on Expansion Joint Materials (D. O. Woolf, chairman) during the past year has prepared several new tentative specifications and methods of testing which have been submitted to the Society. It is now formulating requirements for other materials, particularly joint sealers for cold application.

In connection with the recommendation for publication of the new Tentative Methods of Testing Concrete Joint Sealers (D 1191 - 52 T), accepted on February 15, 1952, the subcommittee submitted the test data shown in Appendix III[11] to indicate the reproducibility of these tentative methods as applied to the Tentative Specifications for Concrete Joint Sealer, Hot-Poured Elastic Type (D 1190 - 52 T). Data for laboratory A were obtained by the manufacturer and those for laboratory B and laboratory C by a state highway department.

RESEARCH ACTIVITIES

In annual reports for the past three years, Committee D-4 has included a general summary of the more important research activities of its subcommittees. Continuing progress in the development of new methods is demonstrated by the new tentative specifications and methods of testing recently issued by the Society, and by the preceding review of subcommittee activities. Of particular interest is the study of methods for testing bituminous mixtures and evaluating their probable performance under service conditions under way by Subcommittees B-2, B-25, and B-26. Another example of a research approach to current problems is the attention being given by Subcommittee B-12 to properties of mineral aggregates which are difficult to measure and are at present not controlled by specification requirements.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. A. Carpenter.
First Vice-Chairman, J. H. Swanberg.
Second Vice-Chairman, A. T. Goldbeck.
Third Vice-Chairman, E. W. Klinger.
Secretary, B. A. Anderton.

This report has been submitted to letter ballot of the committee, which consists of 143 members; 100 members returned their ballots, of whom 93 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. E. PROUDLEY,
Chairman.

B. A. ANDERTON,
Secretary.

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[10] See p. 402.
[11] See p. 412.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Materials for Soil-Aggregate Subbase, Base and Surface Courses (D 1241 - 52 T).*

Tentative Revision of Standard Methods of:

Testing Emulsified Asphalts (D 244 - 49).

These recommendations were accepted by the Standards Committtee on September 5, 1952, and the new tentative and tentative revision appear in the 1952 Book of ASTM Standards, Part 3.

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*Jointly with Committee D-18 on Soils for Engineering Purposes.

APPENDIX I

COOPERATIVE TESTS ON RESIDUE OF 100 PENETRATION

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
SC-3 Road Oil, Sample No. 1							
A	ASTM D 243 - 36[a]	540	77.0	102	130	167+	13.2
	CO_2 Distillation	85	56.8	100	140	167+	17.0
	Vacuum Distillation	75	56.5	100	161	167+	18.5
B	ASTM D 243 - 36	420	78.5	98	100+	100+	13.5
	CO_2 Distillation	55	56.8	101	100+	100+	16.0
	Vacuum Distillation	45	55.5	100	100+	100+	24.5
C	ASTM D 243 - 28 T[b]	260	75.2	102	...	100	12.5
	CO_2 Distillation	...	56.1	99	...	100	14.5
	Vacuum Distillation	...	58.2	108	...	100	23.2
D	ASTM D 243 - 28 T	210	75.4	102	...	150+	8.0
	ASTM D 243 - 36	505	78.4	107	...	150+	10.25
	CO_2 Distillation	55	56.5	92	...	150+	7.0
	Vacuum Distillation	65	56.5	100	...	150+	7.0
E	ASTM D 243 - 36	360	76.8	115	125	135+	16.0
	CO_2 Distillation	120	54.0	87	135	135+	11.0
	Vacuum Distillation	35	56.0	92	135	135	15.0
F	ASTM D 243 - 28 T	205	75.2	94	110+	110+	8.5
	ASTM D 243 - 36	471	77.0	89	110+	110+	8.0
	CO_2 Distillation	85	57.4	95	110+	110+	19.0
	Vacuum Distillation	33	58.7	114	110+	110+	22.0
G	ASTM D 243 - 36	465	76.6	97	150+	150+	8.75
	CO_2 Distillation	65	55.0	92	150	150+	9.0
	Vacuum Distillation	120	55.8	96	150+	150+	7.0
SC-3 Road Oil, Sample No. 2							
A	ASTM D 243 - 36	120	74.0	97	167+	167+	8.8
	CO_2 Distillation	50	72.6	105	167+	167+	26.5
	Vacuum Distillation	35	73.5	102	167+	167+	52.0
B	ASTM D 243 - 36	165	74.8	103	100+	100+	67.0
	CO_2 Distillation	25	73.4	103	100+	100+	64.0
	Vacuum Distillation	40	74.3	102	100+	100+	59.0
C	ASTM D 243 - 28 T	55	74.1	98	...	100	29.4
	CO_2 Distillation	...	72.8	97	...	100	35.6
	Vacuum Distillation	...	73.0	92	...	100	24.4
D	ASTM D 243 - 28 T	25	74.7	103	...	150+	15.0
	ASTM D 243 - 36	95	75.2	107	...	150+	23.5
	CO_2 Distillation	30	74.2	95	...	150+	24.0
	Vacuum Distillation	45	74.2	106	...	150+	23.0
E	ASTM D 243 - 36	120	74.1	95	140	135+	30.0
	CO_2 Distillation	30	74.0	115	115	125	50.0
	Vacuum Distillation	25	74.0	115	140	125	30.0
F	ASTM D 243 - 28 T	24	73.9	98	110+	110+	15.0
	ASTM D 243 - 36	75	73.7	98	110+	110+	25.0
	CO_2 Distillation	17	72.1	100	110+	110+	15.0
	Vacuum Distillation	12	73.4	90	110+	110+	15.0
G	ASTM D 243 - 36	90	73.5	84	150+	150+	11.5
	CO_2 Distillation	25	73.1	95	150+	150+	23.0
	Vacuum Distillation	25	73.2	93	150+	150+	28.0

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[a] 1949 Book of ASTM Standards, Part 3.

[b] *Proceedings*, Am. Soc. Testing Mats, Vol 28 Part I, p. 948 (1928); also 1935 Book of ASTM Tentative Standards, p. 861.

APPENDIX I—*Continued*

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
	SC-3 ROAD OIL, SAMPLE NO. 3						
A	ASTM D 243 - 36	555	78.1	98	162	167+	100
	CO₂ Distillation	55	64.5	100	167+	167+	100+
	Vacuum Distillation	60	65.4	98	167+	167+	100+
B	ASTM D 243 - 36	600	79.0	101	100+	100+	100+
	CO₂ Distillation	45	67.5	100	100+	100+	100+
	Vacuum Distillation	55	68.8	102	100+	100+	100+
C	ASTM D 243 - 28 T	510	77.2	102	...	100	100
	CO₂ Distillation	...	66.5	100	...	100	100
	Vacuum Distillation	...	69.1	105	...	100	100
D	ASTM D 243 - 28 T	152	77.4	103	...	150+	31.5
	ASTM D 243 - 36	430	79.3	105	...	150+	70.5
	CO₂ Distillation	45	67.0	104	...	150+	150+
	Vacuum Distillation	65	66.9	97	...	150+	149.5
E	ASTM D 243 - 36	290	78.7	97	140	135	25.0
	CO₂ Distillation	135	65.0	110	130	130	55.0
	Vacuum Distillation	38	65.5	85	135	135+	50.0
F	ASTM D 243 - 28 T	174	77.4	112	110+	110+	51.0
	ASTM D 243 - 36	423	78.3	100	110+	110+	37.0
	CO₂ Distillation	50	64.7	108	110+	110+	60.0
	Vacuum Distillation	45	67.1	91	110+	110+	75.0
G	ASTM D 243 - 36	420	78.4	88	150+	150+	20+
	CO₂ Distillation	50	66.0	99	150+	150+	65.0
	Vacuum Distillation	100	65.5	86	150+	150+	20+
	SC-3 ROAD OIL, SAMPLE NO. 4						
A	ASTM D 243 - 36	105	83.2	103	124	167+	0
	CO₂ Distillation	45	81.3	103	154	167+	100+
	Vacuum Distillation	45	82.6	105	167+	167+	0[a]
B	ASTM D 243 - 36	135	83.2	101	100+	100+	100+
	CO₂ Distillation	45	82.2	102	100+	100+	100+
	Vacuum Distillation	40	81.1	97	100+	100+	100+
C	ASTM D 243 - 28 T	70	82.9	103	...	100	0
	CO₂ Distillation	...	81.9	103	...	100	100
	Vacuum Distillation	...	83.0	104	...	100	2.0
D	ASTM D 243 - 28 T	23	82.4	95	...	150+	0
	ASTM D 243 - 36	73	83.0	97	...	150+	0
	CO₂ Distillation	20	82.8	108	...	150+	0
	Vacuum Distillation	35	82.1	88	...	150+	0
E	ASTM D 243 - 36	60	82.7	103	135	135	0
	CO₂ Distillation	25	82.5	94	130	125	0
	Vacuum Distillation	20	81.0	99	135+	135	0
F	ASTM D 243 - 28 T	21	82.1	92	110+	110+	0
	ASTM D 243 - 36	63	83.0	97	110+	110+	0
	CO₂ Distillation	20	81.6	96	110+	110+	100+
	Vacuum Distillation	10	83.0	100	110+	110+	0
G	ASTM D 243 - 36	56	82.8	100	150+	150+	0
	CO₂ Distillation	25	81.2	100	150+	150+	0
	Vacuum Distillation	45	82.5	91	150+	150+	0
	SC-3 ROAD OIL, SAMPLE NO. 5						
A	ASTM D 243 - 36	525	77.1	98	160	148	14.0
	CO₂ Distillation	75	67.7	102	167+	167+	33.5
	Vacuum Distillation	90	69.8	103	167+	167+	51.0
B	ASTM D 243 - 36	360	77.7	102	100+	100+	16.0
	CO₂ Distillation	65	69.5	99	100+	100+	67.0
	Vacuum Distillation	40	70.0	100	100+	100+	100+
C	ASTM D 243 - 28 T	315	77.0	99	...	100	13.6
	CO₂ Distillation	...	68.0	98	...	100	44.6
	Vacuum Distillation	...	69.4	97	...	100	73.0

[a] 100+, when specimen cooled in place.

APPENDIX I—*Continued*

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
	SC-3 ROAD OIL, SAMPLE NO. 5—*Continued*						
D	ASTM D 243 - 28 T	140	76.0	100	...	150+	16.5
	ASTM D 243 - 36	315	78.2	106	...	150+	32.0
	CO_2 Distillation	30	69.5	108	...	150+	63.0
	Vacuum Distillation	40	70.5	109	...	150+	47.0
E	ASTM D 243 - 36	420	77.7	102	110	90	26.0
	CO_2 Distillation	75	68.5	91	140+	140+	31.0
	Vacuum Distillation	26	68.0	87	140+	135	28.0
F	ASTM D 243 - 28 T	153	76.5	91	110+	41	11.25
	ASTM D 243 - 36	345	77.3	95	110+	32	13.5
	CO_2 Distillation	40	67.0	92	110+	110+	75+
	Vacuum Distillation	30	69.4	90	110+	110+	47.0
G	ASTM D 243 - 36	325	77.2	89	150+	81	13.0
	CO_2 Distillation	30	78.1	85	150+	150+	64.0
	Vacuum Distillation	45	77.9	87	150+	150+	19.75
	SC-3 ROAD OIL, SAMPLE NO. 6						
A	ASTM D 243 - 36	300	74.5	101	167+	167+	53.5
	CO_2 Distillation	60	65.7	100	167+	167+	73.0
	Vacuum Distillation	45	69.1	95	167+	167+	26.5
B	ASTM D 243 - 36	335	74.6	101	100+	100+	30.0
	CO_2 Distillation	55	60.6	103	100+	100+	21.0
	Vacuum Distillation	40	70.2	103	100+	100+	100+
C	ASTM D 243 - 28 T	170	73.9	99	...	100	26.4
	CO_2 Distillation	...	66.4	93	...	100	50.5
	Vacuum Distillation	...	69.8	106	...	100	30.5
D	ASTM D 243 - 28 T	95	74.0	100	...	150+	13.25
	ASTM D 243 - 36	245	75.0	98	...	150+	26.0
	CO_2 Distillation	30	67.3	99	...	150+	27.0
	Vacuum Distillation	75	68.9	98	...	150+	18.5
E	ASTM D 243 - 36	420	75.0	115	135	125+	25.0
	CO_2 Distillation	105	63.0	115	140+	130	33.0
	Vacuum Distillation	30	66.0	88	130	125	16.0
F	ASTM D 243 - 28 T	81	74.2	113	110+	110+	20.0
	ASTM D 243 - 36	216	74.9	115	110+	110+	20.0
	CO_2 Distillation	35	62.9	86	110+	110+	46.0
	Vacuum Distillation	35	69.8	114	110+	110+	55+
G	ASTM D 243 - 36	240	73.2	87	150+	150+	12.0
	CO_2 Distillation	30	68.0	100	150+	150+	29.0
	Vacuum Distillation	60	66.8	90	150+	150+	15.25
	SC-3 ROAD OIL, SAMPLE NO. 7						
A	ASTM D 243 - 36	210	73.9	100	167+	167+	50.0
	CO_2 Distillation	50	68.3	97	167+	167+	55.0
	Vacuum Distillation	40	71.2	102	167+	167+	61.0
B	ASTM D 243 - 36	330	74.3	102	100+	100+	75.0
	CO_2 Distillation	50	70.5	98	100+	100+	100+
	Vacuum Distillation	45	71.5	98	100+	100+	100+
C	ASTM D 243 - 28 T	215	73.4	98	...	100	35.0
	CO_2 Distillation	...	66.6	97	...	100	86.3
	Vacuum Distillation	...	71.2	102	...	100	100
D	ASTM D 243 - 28 T	65	73.2	98	...	150+	20.75
	ASTM D 243 - 36	167	74.1	102	...	150+	35.5
	CO_2 Distillation	25	70.7	97	...	150+	118
	Vacuum Distillation	55	70.6	90	...	150+	71.0
E	ASTM D 243 - 36	240	74.5	88	140	95	20.0
	CO_2 Distillation	45	66.0	99	140+	140	49.0
	Vacuum Distillation	28	69.0	95	140+	140	65.0
F	ASTM D 243 - 28 T	60	72.7	94	110+	110+	36.0
	ASTM D 243 - 36	186	74.2	95	110+	110+	26.0
	CO_2 Distillation	25	68.7	110	110+	110+	75+
	Vacuum Distillation	22	71.1	101	110+	110+	50+
G	ASTM D 243 - 36	168	73.1	89	150+	136	13.5
	CO_2 Distillation	25	70.3	92	150+	150+	74.0
	Vacum Distillation	45	70.5	99	150+	150+	20+

APPENDIX I—*Continued*

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
	SC-3 Road Oil, Sample No. 8						
A	ASTM D 243 - 36	360	74.7	97	161	167+	12.7
	CO_2 Distillation	50	61.9	98	116.5	167+	32.0
	Vacuum Distillation	50	63.7	94	167+	167+	16.0
B	ASTM D 243 - 36	360	75.5	102	100+	100+	25.5
	CO_2 Distillation	40	64.5	98	100+	100+	29.0
	Vacuum Distillation	45	63.2	102	100+	100+	49.0
C	ASTM D 243 - 28 T	255	74.1	103	...	100	11.9
	CO_2 Distillation	...	63.1	92	...	100	15.2
	Vacuum Distillation	...	65.1	104	...	100	28.1
D	ASTM D 243 - 28 T	150	73.8	103	...	150+	13.0
	ASTM D 243 - 36	440	76.0	101	...	150+	15.0
	CO_2 Distilation	55	64.5	94	...	150+	14.0
	Vacuum Distilation	45	64.4	94	...	150+	15.0
E	ASTM D 243 -36	530	75.4	105	135	135	25.0
	CO_2 Distillation	80	64.5	96	125+	125+	19.0
	Vacuum Distillation	31	63.0	95	135	135	23.0
F	ASTM D 243 - 28 T	159	73.1	95	110+	110+	6.75
	ASTM D 243 - 36	402	75.0	95	110+	110+	9.0
	CO_2 Distillation	50	64.4	103	110+	110+	60+
	Vacuum Distillation	50	64.2	93	110+	110+	14.0
G	ASTM D 243 - 36	367	73.6	83	150+	126	8.5
	CO_2 Distillation	50	62.5	86	150+	150+	13.0
	Vacuum Distillation	75	64.8	100	150+	150+	14.0
	SC-3 Road Oil, Sample No. 9						
A	ASTM D 243 - 36	750	79.8	100	85.5	24	9.7
	CO_2 Distillation	80	66.4	106	132	167+	36.5
	Vacuum Distillation	85	66.5	103	167+	152.5	10.7
B	ASTM D 243 - 36	900	80.9	99	66	34	9.0
	CO_2 Distillation	75	68.3	102	100+	100+	42.0
	Vacuum Distillation	35	68.5	103	100+	100+	21.5
C	ASTM D 243 - 28 T	320	79.1	101	...	36	8.8
	CO_2 Distillation	...	66.0	104	...	100	48.2
	Vacuum Distillation	...	67.6	100	...	100	17.0
D	ASTM D 243 - 28 T	310	79.7	96	96	24	6.75
	ASTM D 243 - 36	765	81.3	102	79	31	10.5
	CO_2 Distillation	70	67.0	100	...	150+	16.0
	Vacuum Distillation	115	67.2	104	...	150+	16.5
E	ASTM D 243 - 36	470	80.9	113	115	30	10.0
	CO_2 Distillation	120	64.5	109	125	125	11.0
	Vacuum Distillation	40	64.0	86	135+	85	12.0
F	ASTM D 243 - 28 T	275	79.3	106	55	20	5.5
	ASTM D 243 - 36	612	80.5	115	56	27	8.75
	CO_2 Distillation	55	66.4	114	110+	84	26.0
	Vacuum Distillation	75	67.5	115	110+	97	17.75
G	ASTM D 243 - 36	630	79.4	100	99	27	6.75
	CO_2 Distillation	60	66.0	94	150+	150+	14.0
	Vacuum Distillation	180	66.3	99	150+	129	12.25
	SC-3 Road Oil, Sample No. 10						
A	ASTM D 243 - 36	780	80.2	97	167+	101	8.7
	CO_2 Distillation	105	62.5	101	167+	167+	22.5
	Vacuum Distillation	115	63.3	100	167+	167+	30.5
B	ASTM D 243 - 36	720	80.7	100	100+	100+	15.0
	CO_2 Distillation	75	63.1	98	100+	100+	40.0
	Vacuum Distillation	45	62.8	102	100+	100+	100+
C	ASTM D 243 - 28 T	420	79.6	103	...	79	20.5
	CO_2 Distillation	...	62.7	92	...	100	26.8
	Vacuum Distillation	...	63.8	97	...	100	57.3
D	ASTM D 243 - 28 T	290	79.2	105	...	150+	10.25
	ASTM D 243 - 36	720	81.0	103	150+	97.5	12.75
	CO_2 Distillation	70	62.8	96	...	150+	15.25
	Vacuum Distillation	80	63.3	98	...	150+	15.0

APPENDIX I—*Continued*

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
SC-3 ROAD OIL. SAMPLE NO. 10—*Continued*							
E	ASTM D 243 - 36	540	80.5	112	105	104	16.0
	CO_2 Distillation	120	63.0	100	140	135	20.0
	Vacuum Distillation	45	63.5	105	135	135	15.0
F	ASTM D 243 - 28 T	324	79.0	93	110+	55	5.75
	ASTM D 243 - 36	651	80.6	103	110+	73	32.0
	CO_2 Distillation	60	63.4	96	110+	110+	25.0
	Vacuum Distillation	120	62.9	106	110+	110+	28.0
G	ASTM D 243 - 36	630	79.7	95	150+	57	9.0
	CO_2 Distillation	65	62.0	85	150+	150+	11.0
	Vacuum Distillation	240	61.2	94	150+	150+	12.0
SC-3 ROAD OIL, SAMPLE NO. 11							
A	ASTM D 243 - 36	450	76.4	95	167+	108	12.5
	CO_2 Distillation	60	65.9	92	111	167+	30.5
	Vacuum Distillation	55	66.8	93	167+	167+	15.0
B	ASTM D 243 - 36	420	82.3	98	100+	100+	22.5
	CO_2 Distillation	60	67.0	99	100+	100+	27.0
	Vacuum Distillation	35	67.5	103	100+	100+	55.0
C	ASTM D 243 - 28 T	255	77.5	105	...	100	13.2
	CO_2 Distillation	...	66.6	96	...	100	18.0
	Vacuum Distillation	...	69.7	108	...	100	30.1
D	ASTM D 243 - 28 T	140	77.3	102	77	114	12.0
	ASTM D 243 - 36	415	78.3	105	104	140	12.5
	CO_2 Distillation	35	67.4	97	141	150+	11.0
	Vacuum Distillation	50	67.8	93	146	150+	9.25
E	ASTM D 243 - 36	480	77.2	112	100	100	20.0
	CO_2 Distillation	135	66.5	85	110	110	11.0
	Vacuum Distillation	34	69.0	85	120+	100	35.0
F	ASTM D 243 - 28 T	162	76.9	106	110+	110+	11.0
	ASTM D 243 - 36	378	77.8	114	110+	110+	7.25
	CO_2 Distillation	50	65.3	96	110+	110+	30.0
	Vacuum Distillation	50	66.9	87	110+	110+	8.0
G	ASTM D 243 - 36	375	76.6	94	87	62	9.5
	CO_2 Distillation	45	68.9	92	112	150+	18.0
	Vacuum Distillation	90	66.7	86	150+	150+	10.5
SC-3 ROAD OIL, SAMPLE NO. 12							
A	ASTM D 243 - 36	270	76.4	103	161	167+	16.0
	CO_2 Distillation	90	71.1	92	167+	167+	15.0
	Vacuum Distillation	90	70.4	101	167+	167+	24.5
B	ASTM D 243 - 36	345	77.3	103	100+	100+	11.0
	CO_2 Distillation	55	73.2	102	100+	100+	19.0
	Vacuum Distillation	45	73.1	101	100+	100+	35.5
C	ASTM D 243 - 28 T	180	77.3	100	...	100	11.5
	CO_2 Distillation	...	72.1	99	...	100	20.4
	Vacuum Distillation	...	72.9	105	...	100	21.5
D	ASTM D 243 - 28 T	85	76.7	100	...	150+	9.0
	ASTM D 243 - 36	260	77.5	93	...	150+	10.0
	CO_2 Distillation	45	71.7	92	...	150+	11.5
	Vacuum Distillation	60[a]	74.9	144	...	150+	34.5
E	ASTM D 243 - 36	240	76.5	89	135	110	12.0
	CO_2 Distillation	130	72.0	104	130	125	16.0
	Vacuum Distillation	50	71.0	104	145	130	30.0
F	ASTM D 243 - 28 T	93	76.6	98	110+	110+	6.75
	ASTM D 243 - 36	216	77.2	108	110+	110+	6.0
	CO_2 Distillation	45	72.0	102	110+	105	20.0
	Vacuum Distillation	85	72.2	110	110+	110+	16.25
G	ASTM D 243 - 36	210	76.8	91	150+	150+	8.5
	CO_2 Distillation	50	71.8	99	150+	150+	18.0
	Vacuum Distillation	150	72.6	145	145	147	18.75

[a] No more distillate.

APPENDIX I—*Continued*

Laboratory	Method	Time, min	Residue, per cent	Penetration	Ductility, cm		
					77 F, 5 cm per min	60 F, 5 cm per min	39.2 F, 1 cm per min
SC-3 ROAD OIL, SAMPLE NO. 13							
A	ASTM D 243 - 36	570	73.4	102	167+	167+	20.5
	CO_2 Distillation	70	63.8	101	152	167+	93.0
	Vacuum Distillation	45	66.7	104	167+	167+	94.0
B	ASTM D 243 - 36	525	74.2	99	100+	100+	38.0
	CO_2 Distillation	40	64.9	102	100+	100+	22.0
	Vacuum Distillation	40	66.7	102	100+	100+	100+
C	ASTM D 243 - 28 T	270	72.9	95	...	100	17.5
	CO_2 Distillation	...	63.8	96	...	100	83.5
	Vacuum Distillation	...	66.7	97	...	100	100.0
D	ASTM D 243 - 28 T	180	71.6	90	...	150+	18.0
	ASTM D 243 - 36	555	74.8	94	...	150+	28.75
	CO_2 Distillation	35	65.4	94	...	150+	113.0
	Vacuum Distillation	85	65.2	99	...	150+	78.0
E	ASTM D 243 - 36	420	74.0	109	135	135+	25.0
	CO_2 Distillation	75	67.0	114	140	130	58.0
	Vacuum Distillation	30	65.5	96	135+	135+	45.0
F	ASTM D 243 - 28 T	168	72.6	106	110+	110+	44.0
	ASTM D 243 - 36	402	74.0	106	83	79	36.0
	CO_2 Distillation	43	62.7	104	110+	110+	50+
	Vacuum Distillation	32	67.1	108	110+	110+	100+
G	ASTM D 243 - 36	420	73.6	95	144	147	20+
	CO_2 Distillation	40	63.0	85	150+	150+	104.0
	Vacuum Distillation	75	64.7	86	150+	150+	20.0
SC-3 ROAD OIL, SAMPLE NO. 14							
A	ASTM D 243 - 36	540	77.5	99	167+	85	9.8
	CO_2 Distillation	90	64.8	103	167+	167+	16.0
	Vacuum Distillation	85	65.4	101	167+	167+	26.5
B	ASTM D 243 - 36	720	77.2	102	100+	84	11.5
	CO_2 Distillation	65	65.4	102	100+	100+	13.5
	Vacuum Distillation	75	66.1	102	100+	100+	48.0
C	ASTM D 243 - 28 T	240	76.2	98	...	37	10.7
	CO_2 Distillation	...	64.7	97	...	100	14.0
	Vacuum Distillation	...	65.9	105	...	100	52.0
D	ASTM D 243 - 28 T	200	76.0	101	147	66	9.0
	ASTM D 243 - 36	525	79.0	102	140	114	10.0
	CO_2 Distillation	60	65.6	99	...	150+	16.5
	Vacuum Distillation	95	65.7	109	...	150+	10.0
C	ASTM D 243 - 36	360	76.8	104	135	135	8.0
	CO_2 Distillation	60	63.0	86	140	135	10.0
	Vacuum Distillation	35	62.5	98	135+	125	16.0
F	ASTM D 243 - 28 T	204	76.8	108	105	18	9.0
	ASTM D 243 - 36	462	77.9	108	97	15	9.0
	CO_2 Distillation	50	63.5	85	110+	110+	15.0
	Vacuum Distillation	40	66.4	107	110+	110+	36.0
G	ASTM D 243 - 36	464	76.4	95	109	24	7.5
	CO_2 Distillation	55	64.5	94	150+	150+	16.0
	Vacuum Distillation	45	65.9	99	150+	150+	27.0

APPENDIX II

STRIPPING TEST FOR BITUMEN-AGGREGATE MIXTURES[1]

NOTE—This report reviews cooperative studies by Subcommittee B-26 on Effect of Water on Bituminous Coated Aggregates in an effort to standardize a visual estimation method applicable to the stripping of bitumen in bitumen-aggregate mixtures.

Methods for evaluating the resistance to displacement by water of the bitumen in bitumen-aggregate mixtures have been included in many specifications in recent years. This has been brought about by several factors. Field experience has indicated that certain bitumens and certain aggregates, when used in paving mixtures, vary in their ability to maintain the bituminous coating in the presence of water. Thus, a suitable laboratory test method would permit the selection of the best combination of bitumen, available aggregate, and type of paving mixture to use for specific service requirements. Furthermore, compensation for the occasional deficiency of a specific aggregate or bitumen may be attained by the use of anti-stripping additives, either applied to the aggregate or incorporated in the bitumen. The effectiveness of such treatments must be established by results in the field and a laboratory test developed to rate this effectiveness quantitatively.

The development of a standardized method has been the subject of study for several years by Subcommittee B-26 of ASTM Committee D-4. The major effort has been concerned with the development of a method applicable to mixtures made with cold-application bitumens of the liquid or cut-back type. These present a greater problem both in the field and in the laboratory testing than hot-application bitumens. Furthermore, ASTM Tentative Method of Test for Effect of Water on the Cohesion of Compacted Bituminous Mixtures (D 1075 – 49 T)[1a] is available in the interim for rating the over-all effect of water on mixtures made with hot-mix bitumens of the semi-solid or solid types. In the course of this work, twelve laboratories of consumer and producer organizations represented on the subcommittee have participated in cooperative test work. This study covered three phases:

1. A survey and review of published methods to determine the test conditions most generally considered desirable. Based on this survey and the experience of the subcommittee members, a test procedure was agreed upon.

2. Numerous cooperative tests were made with different bitumens and aggregates to improve the test procedure and define more clearly the conditions necessary for best reproducibility.

3. Mechanical type, direct rating methods for measuring the degree of stripping have not yet been developed to the extent where they can be readily applied. Reliance must therefore be placed on visual estimation where reproducibility is mainly dependent on the ability of the rater. Thus, the last phase of the work has included a survey of the limitations of the visual estimation method.

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[1] This report is published as information only.

[1a] 1949 Book of ASTM Standards, Part 3.

Survey of Existing Methods:

The need for a standard test is apparent from the number of procedures now available. For example, a review of published methods in 1947 showed 31 different procedures. In many instances, these form a part of specifications for "special" bituminous materials purchased in the United States. Generally, such specifications have only been stipulated where specific conditions of aggregate availability, drainage conditions, or unusual problems of construction or exposure make it desirable to be certain of adequate resistance to the stripping action of water. It should be pointed out that, in the majority of paving products, the usual aggregates and bitumens have been adequate to ensure satisfactory service performance from the standpoint of resistance to stripping.

The survey revealed certain test conditions common to the majority of methods. These were:

1. *Test Aggregate.*—Generally a gradation within the $\frac{1}{2}$ to $\frac{1}{4}$-in. standard sieve is specified. The choice of aggregate type varies with local conditions and requirements.

2. *Mixture Preparation:* (*a*) *Proportions.*—Generally 5 to 7 per cent (by weight) of bitumen is incorporated.

(*b*) *Mixing Conditions.*—With liquid or cut-back type bitumens, the mixture is made with aggregate at room temperature and the bitumen is heated to provide adequate fluidity.

(*c*) *Mixing Time.*—One to three minutes—sufficient to provide adequate coating without excessive solvent loss in the case of cut-back bitumens.

(*d*) *Preconditioning.* — The finished mixture is mildly cured, generally overnight at temperatures in the range of 77 to 140 F.

3. *Water Exposure Conditions:* (*a*) *Medium.*—Distilled water; preferably with pH control by double distillation; electrolyte additions not permissible.

(*b*) *Conditions.*—Total immersion in distilled water, usually for 18 to 24 hr; mechanical action generally not considered sufficiently reproducible to provide consistent results.

4. *Evaluation.*—Visual estimation of the percentage of visible aggregate surface that remains coated in the undisturbed mixture while still submerged in distilled water.

5. *Rating.*—Generally expressed as "stripping resistance"; defined as the percentage of visible surface area still coated with bitumen.

As previously stated, the above conditions are those specified in the majority of methods reviewed and do not reflect the specific conditions of any single method. Other modifications were encountered. Some methods stipulate that completely cured mixtures be exposed to boiling distilled water or to boiling solutions of special electrolytes (Riedel and Weber test); some specify mechanical agitation or hand stirring to accelerate stripping or facilitate removal of coatings that are not firmly adherent.

Selection of Test Conditions:

After consideration of the above "average" conditions for a stripping test and the actual field conditions in which water-promoted stripping might occur in bitumen-aggregate mixtures, a preliminary procedure was agreed upon for application to dry and to wet aggregates. A number of round-robin tests were conducted. At first the reproducibility among the various cooperating laboratories left much to be desired. However, certain features of the test conditions were gradually improved upon and more accurately defined. For example, the temperature conditions and mixing time for preparation of the test mixture had to be closely defined. Otherwise, variations in the degree of curing would lead to inconsistent results, especially with cut-back bitumens. The procedure for preconditioning (mild curing) of the test mixture had to be closely outlined for the same reason. Ultimately the procedure outlined in the last section of this report was established.

Finally, ten laboratories conducted a series of cooperative tests using two aggregates—a New Jersey traprock and a dolomite rock from Virginia. Ratings were made with six different bituminous cut-backs, ranging from rapid-curing to slow-curing types. Each laboratory conducted two or three separate tests with each bitumen and aggregate. In many cases, the final stripping resistance ratings were made by several operators in each laboratory.

The average results reported by each laboratory for tests made with dry aggregate are given in Table I. It will be noted that considerable variation is apparent among the different laboratories. The closest agreement is 95–99 stripping resistance for sample MC-B on traprock, whereas the poorest is the 45–89 for sample SC-A on the dolomite. Generally, there is no indication that more consistent values have been obtained with either the faster curing or the slower curing bitumens. Using all individual values reported, the standard deviation for each series has been calculated, and this will be discussed in a later section.

In the wet-aggregate test, the agreement among laboratories was extremely poor, as noted in Table II. While it is evident that laboratories A, C, and F generally reported results lower than the other seven, exclusion of their results from the present series would not improve the range of ratings to an acceptable level. Minor differences in the intensity of mixing, slight variations in the degree of curing, and other factors are undoubtedly more critical in a wet aggregate-bitumen test. This is evident in that the results reported by an individual laboratory are frequently quite consistent, probably because variations in procedure and technique are minimized through the use of the same technicians.

In view of the lack of reproducibility, various refinements in technique have been tried, but with little improvement over the results obtained with the established procedure outlined in the last section of this report. A brief summary of the modifications and a general appraisal of their value follows.

1. *Standard Area Photographs.*—As an aid for training, and for comparison with specimens to be rated, a series of photographs was made with a black background having small white areas of known total area. An attempt was made to have the random positioning and sizes of the white areas approximate the actual appearance of stripped bitumen-aggregate mixtures. Transparent gray masks were furnished to adjust the white areas to the approximate color of the stone being investigated. These were tried by the cooperating laboratories with the general conclusion that (*a*) the photographs were an aid in training raters, but (*b*) the appearance in general did not appear "natural" and thus raters did not find them an assistance for direct comparison with actual specimens.

2. *Weighted Average Evaluation.*—This is simply a further refinement of the method. Each stone in the test mixture is individually rated while under water and separated into the following groups:

Group	Rating	Average Value[a]
1	100	100
2	90 to 99	95
3	80 to 89	85
4	70 to 79	75
5	50 to 69	60
6	30 to 49	40
7	10 to 29	20
8	0 to 9	5

[a] Used in calculation of weighted average.

The eight piles are then dried and finally weighed. The "weighted average" rating is determined by multiplying the weight of

TABLE I.—COOPERATIVE STRIPPING TESTS—VISUAL ESTIMATION METHOD—DRY AGGREGATE TEST.

Aggregate	TRAP ROCK (NEW JERSEY)						DOLOMITE (VIRGINIA)				
Bituminous Material	RC-A	RC-B	MC-A	MC-B	SC-A	SC-B	RC-A	MC-A	MC-B	SC-A	SC-C
Average Rating[a]											
Laboratory A	(55)	(73)	87	97	73	96	90	58	58	45	48
Laboratory B	99	99	93	99	93	97	99	94	92	78	87
Laboratory C	86	93	93	96	94	96	..	..	..	..	..
Laboratory D	98	98	96	99	92	97	99	95	96	89	85
Laboratory E	99	99	98	99	98	97	..	..	..	..	..
Laboratory F	80	91	90	96	87	90	95	80	83	80	77
Laboratory G	99	97	94	97	87	91	..	..	..	..	..
Laboratory H	100	100	95 (73)	97	70	80	98	70	80	50	60
Laboratory J	93	97	83	95	83	98	..	..	..	..	..
Laboratory K	97	99	90	95	87	80	..	..	..	..	..
No. of Evaluations	28	28	32	32	32	32	11	11	14	12	14
Overall Average	94	96.7	90.4	96.6	86.1	91.3	97	83	84	71	73
Standard Deviation	9.2	3.7	7.6	0.9	9.7	7.2	3.6	14.9	11.8	17	14
Range of Ratings	80–100	91–100	83–98	95–99	70–98	80–97	90–99	58–95	58–96	45–89	48–87

[a] Figures represent the average of all tests by each laboratory; the individual values were used in calculating standard deviation. Figures in parentheses appear erroneous and have not been used.

TABLE II.—COOPERATIVE STRIPPING TESTS—VISUAL ESTIMATION METHOD—WET AGGREGATE TEST.

Aggregate	TRAP ROCK (NEW JERSEY)					
Bituminous Material	RC-A	RC-B	MC-A	MC-B	SC-A	SC-B
Average Rating						
Laboratory A	35	43	79	89	78	78
Laboratory B	88	93	85	98	94	89
Laboratory C	69	66	79	96	81	96
Laboratory D	80	86	100–	100–	99	99
Laboratory E	98	99	95	99	94	96
Laboratory F	33	27	60	87	40 (90)	83
Laboratory G	86	87	89	93	89	94
Laboratory H	90	95	98	100	95	98
Laboratory J	90	90	80	98	80	98
Laboratory K	93	90	95	95	88	83
Range of Ratings	33–98	27–99	60–99	87–100	40–99	78–99
Range of Ratings, excluding A, C & F	80–98	86–99	80–99	93–100	89–99	83–99
FOLLOWING DATA CALCULATED ON TOTAL OBSERVATIONS, WEIGHING EACH OBSERVATION EQUALLY						
CASE NO. I.—VISUAL ESTIMATION ONLY—ALL COOPERATORS						
(1) Overall Average	76	78	86	95	86	90
(2) Standard Deviation	22.4	21.8	8.4[a]	4.5[a]	8.7	8.4
CASE NO. II.—VISUAL ESTIMATION ONLY—A, C, & F OMITTED						
(1) Overall Average	88	90	90	96	90	92
(2) Standard Deviation	8.4	7.3	7.7	3.4[a]	5.9[a]	7.3
CASE NO. III.—VISUAL & COMPARATIVE RESULTS—A, C, & F OMITTED						
(1) Overall Average	88	90	90	96	89	92
(2) Standard Deviation	7.6	6.4	6.6	3.1[a]	5.0[a]	6.8

[a] One (1) observation omitted.

each pile by the average stripping value for that group. These values are added together and then divided by the total weight of sample.

Surprisingly, this procedure did not improve reproducibility among laboratories over that obtained by visual estimation of the total specimen. Furthermore, it is extremely tedious and not applicable to mixtures where the bitumen film is soft and difficult to handle.

3. *100 per cent Coated Evaluation.*—This is a modification of the weighted average evaluation (item 2). The rating is based on the total weight of perfectly coated stones (group 1 above) times 100 and divided by the total weight of sample. The deviation with this modification was not improved.

4. *Dye Absorption Technique.*—Dyes, such as Safranine B, are absorbed by uncoated aggregate but not by bitumen. Thus contacting a bitumen-aggregate mixture with a standard water solution of the dye should provide a colorimetric method for determining the extent of uncoated surface. One member laboratory developed methods for establishing a standard color curve for various aggregates, and for direct optical measurement of color by the spectrophotometer or photovoltmeter. On known mixtures of bare aggregate and fully cured, coated aggregate, this method proved very precise. When applied to mixtures prepared according to the established procedure, the stripping resistance values were higher than those readily apparent by visual estimation. It was found that an interfering but semi-transparent layer of resinous material from the bitumen still remained on the areas which would be considered stripped. Dye absorption in such areas was decreased, thus resulting in abnormally high stripping resistance. No satisfactory method of overcoming this interference was developed, and further development work of this nature was discontinued.

Suffice to say that considerable but unintentional variations in technique can exist between different laboratories and thus cause, at best, only limited reproducibility with the static immersion-visual estimation procedures now available—whether wet or dry aggregate is specified. The test data presented here indicate that the reproducibility problem decreases at higher stripping resistance values.

Studies of Visual Estimation Technique:

There has been considerable question whether the variation in test results might be a fault of the visual estimation technique itself. Does the usual technician have the ability to rate consistently a mixture of partly coated aggregate, even with training? What are the limitations of visual estimation as applied to this problem?

To determine the aptitude of individuals for visual estimation, a series of slides was made up comprising a black background with small holes of known total area. These were projected on a screen and 23 different individuals attending a subcommittee meeting recorded their rating of the actual area covered on each slide. This group included members who had gained some training in the course of the cooperative studies, as well as a number of visitors with little experience of this type. Typical results are listed in Table III for four of the nine slides.

It is quite evident that considerable variation in the ratings occurred with a mixed group of this type. The normal pattern is shown in that it is easier to rate areas that are closer to perfection (that is, fully covered or fully uncovered), as noted on Slides 2 and 9. This is better illustrated in Fig. 1 by the plot marked "Aptitude Tests," where the standard deviation encountered with each of the nine slides is plotted against the "average stripping rating." The latter is the same as the "actual area covered" value shown in Table III. Included are the standard deviations calculated for the dry-aggregate tests of Table I (cooperative tests with traprock and dolomite). Comparison of the two deviation plots illustrates how much of the variation with the attached test method can be considered due to the inherent error in visual estimation, and what part may be credited to slight variations in the technique of preparing the mixtures, curing, etc. For example, bitumens with an average rating of 80 stripping resistance have a deviation of ±13 in the cooperative tests. About 50 per cent of this (7 deviation) is inherent in visual estimation itself.

TABLE III.—VISUAL ESTIMATION—APTITUDE TESTS.

	Rating of Slides of Known Value								Mean Deviation for 9 Slides
Slide Number	2		5		7		9		
Actual Area Covered	11		41		78		94		
Estimator	*R**	*D**	*R*	*D*	*R*	*D*	*R*	*D*	
1	5	−6	25	−16	55	−23	90	−4	13.8
2	10	−1	45	+4	85	+7	93	−1	3.1
3	11	0	53	+12	73	−5	88	−6	5.0
4	8	−3	35	−6	70	−8	95	+1	6.5
5	5	−6	45	+4	85	+7	95	+1	6.4
6	10	−1	40	−1	75	−3	90	−4	2.3
7	10	−1	35	−6	90	+12	95	+1	5.4
8	8	−3	35	−6	80	+2	95	+1	5.5
9	10	−1	50	+9	80	+2	95	+1	5.4
10	20	+9	80	+39	75	−3	95	+1	10.1
11	5	−6	55	+14	80	+2	95	+1	6.3
12	15	+4	50	+9	85	+7	85	−9	6.2
13	6	−5	25	−16	65	−13	95	+1	12.2
14	10	−1	75	+34	85	+7	90	−4	14.1
15	10	−1	45	+4	80	+2	92	−2	3.1
16	15	+4	50	+9	85	+7	92	−2	4.9
17	10	−1	60	+19	80	+2	90	−4	5.7
18	5	−6	30	−11	75	−3	90	−4	9.5
19	5	−6	45	+4	60	−18	95	+1	4.6
20	8	−3	45	+4	85	+7	94	0	3.3
21	5	−6	30	−11	75	−3	90	−4	7.7
22	15	+4	45	+4	85	+7	90	−4	4.5
23	5	−6	50	+9	75	−3	90	−4	6.9
Mean Deviation from True Value	3.7		10.7		6.6		2.7		
Standard Deviation from True Value	4.5		14.6		8.4		3.4		

* *R*—Estimated value; *D*—Deviation from true value.

Training can decrease the deviation due to visual estimation alone. The curve marked Laboratory X illustrates this when compared with the Aptitude Test relationship. In this instance, the deviations are from results reported by five different individuals who had been trained in visual estimation. Results on a total of 124 bitumen-aggregate mixtures exhibiting from 20 to 95 average stripping resistance are represented. Strict interpretation of Fig. 1 would indicate that training has had little effect when the *average* stripping resistance exceeds 80. However, it should be pointed out that the variations between raters on individual samples in the Laboratory X series were much smaller than in the case of the cooperative test series. Thus, training of the raters does have an advantage.

In any case, the data illustrate that a considerable portion of the variance among laboratories is due to an inherent error in rating the specimens by visual estimation. As shown in the following summary tabulation, at least 50 per cent of the deviation for samples averaging greater than 80 stripping resistance is due to the inherent inability of different individuals visually to rate specimens the same.

Average Stripping Resistance, per cent	Standard Deviation[a]		
	Total	Caused by Visual Estimation	
		Partly Trained	With Training
95........	4.7	3.0	3.5
90........	7.5	4.7	4.7
80........	13.3	7.2	6.3
70........	17.0	9.2	7.3

[a] Two out of three tests at the average stripping resistance will agree within the deviation shown.

This discussion of variance among laboratories is not a condemnation of static immersion stripping tests employing visual estimation rating methods. Rather, it should serve to point out the lack of precision to laboratories who may need to employ similar methods for rating aggregates or bitumens. For example, the standard deviations given above indicate the variation from the average that will be encountered in two tests out of three. The third test may possibly fall outside these limits. This is illustrated by the results on RC-A bitumen and traprock given in Table I. Of the nine sets considered, all but one fell within the deviation limits. Laboratory F reported an average of 80 stripping resistance, which exceeded the standard deviation limits.

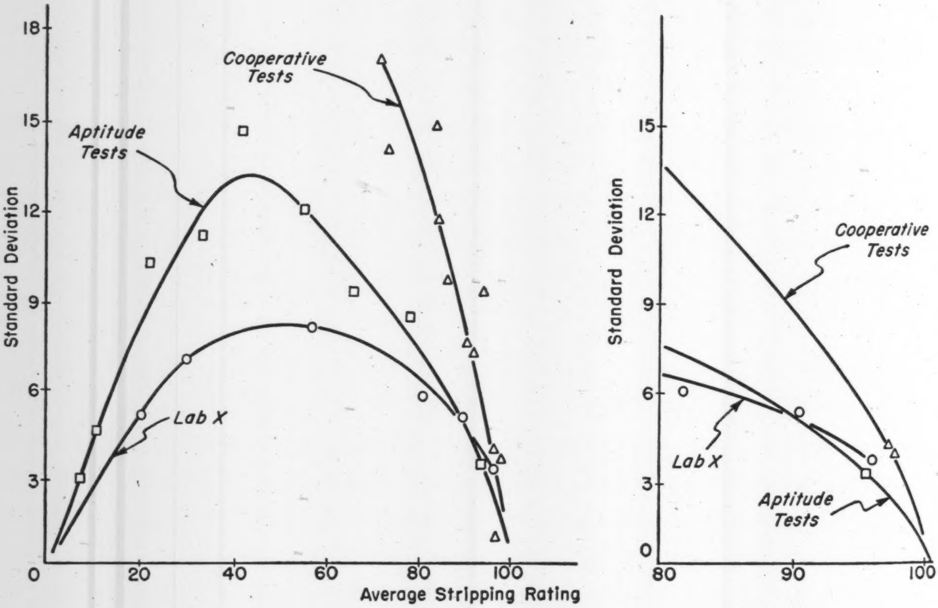

FIG. 1.—Inherent Error in Visual Estimation Technique, Stripping Ratings *versus* Standard Deviation.

Basically, we need a direct method for evaluating stripping tendencies without recourse to visual estimation. This has been the subject of continuing development by many organizations throughout the world. For example, the present effort of Subcommittee B-26 is being directed toward several methods which may be the answer to the problem.

Special equipment is being developed by one member to permit optical measurements by vertical reflectance, oblique reflectance having been found unreliable because of scattering effects. Another member is studying the use of radioactive tracers deposited on the aggregate before coating. The radiation intensity of the immersion water would provide a direct reading of the amount of tracer removed from those areas of the aggregate from which the bitumen has been stripped. Until these or other methods are available, the recourse is to use a static immersion, visual method as outlined herein with due regard to its lack of precision.

Conclusion:

Extensive cooperative tests have resulted in a static immersion, visual estimation method for rating the stripping resistance of bituminous-aggregate mixtures prepared with liquid or cutback bitumens. This procedure may be applied to the relative rating of different aggregates or different bitumens. However, this method is not proposed for standardization by ASTM since the precision is indicated to be inadequate. The lack of precision is greatly influenced by the inability of individuals visually to estimate the correct degree of stripping. A more precise, direct procedure is needed which will be independent of the personal element. Until this is developed, the method given in this report may be used provisionally and with due regard to the limitations on its precision.

STATIC IMMERSION STRIPPING RESISTANCE TEST

Scope

1. This method covers the test for measuring the resistance of bituminous films on coated aggregate towards loosening and removal by action of water or moisture. The procedure applies to liquid and semi-solid bitumens, and emulsified asphalts.

Outline of Method

2. The method consists in coating prewashed, selected aggregate of specified grading with 5.5 per cent of the liquid or semi-solid bitumen, or 8 per cent of emulsified asphalt. The aggregate and bituminous material are preheated when necessary to obtain satisfactory coating and the mixture may be subsequently cured, depending upon the bituminous material employed. The coated aggregate is immersed for 16 to 24 hr in distilled water of 6.0 to 7.0 pH at room temperature for liquid bitumens, and at an elevated temperature (140 F) for the semi-solid and emulsified bituminous materials. The stripping resistance is reported as the percentage of the area of the aggregate on which the coating is retained.

Materials

3. (*a*) *Aggregate.*—In case the stripping resistance of the bituminous material for a given job is to be evaluated, a representative sample of the aggregate to be used on the job is to be employed. Otherwise, one aggregate should be selected as the "standard." It should preferably be a local aggregate on which the field performance as regards stripping is known.

The size of the standard aggregate shall be such that 100 per cent passes a ⅜-in. sieve and is retained on a ¼-in. sieve.

Dust and fines shall be removed by washing with distilled water. The washed aggregate is allowed to air-dry to remove the greater portion of the surface moisture and then oven-dried at 275 to 300 F to constant weight. The washed and dried aggregate shall be stored at room temperature in air-tight containers until desired for use.

(*b*) *Distilled Water.*—The distilled water to be used in washing the aggregate and conducting the stripping tests shall be the ordinary laboratory product reboiled or redistilled, if necessary, so that it shall have a pH of 6.0 to 7.0. No electrolytes of any kind shall be used to obtain the required pH.

Apparatus

4. The apparatus shall consist of the following:

(*a*) *Containers* having rounded corners, such as seamless tin cans, 16-oz capacity.

(*b*) *Scales* capable of weighing up to 500 g within ±0.1 g.

(*c*) *Steel spatula* having a stiff blade approximately 1 in. in width and 4 in. in length.

(*d*) *Glass containers.*—A quantity of 600-ml. glass containers.

(*e*) *Constant temperature ovens* capable of maintaining a temperature within ±5 F at an oven temperature of 140 F and 300 F. (A convection type similar to Cenco triple wall series 95105 and 95205 is recommended.)

Preparation of Bitumen-Aggregate Mixtures:

5. (*a*) *Liquid Bitumens and Emulsified Asphalts—Dry Aggregate Test.*—To 100 g dry aggregate in the tin container, liquid bituminous material is added in an amount equal to 5.5 ± 0.2 per cent for the liquid bitumen or 8 per cent for emulsified asphalt. The bituminous material and aggregate are vigorously mixed manually for 2 min in the open container by means of the stiff spatula. In mixing the liquid bitumen and the aggregate, both should be at the same temperature. For liquid and cut-back asphalts (but not emulsified products), the mixing is conducted at room temperature for grades 0 to 2, at 125 F for grades 3 to 4, and at 150 F for grade 5 material. For emulsified asphalts, in which case only the quick-breaking grades shall be used, the aggregate shall be at 300 F before adding and mixing the bituminous material.

The coated aggregate is allowed to cure at 140 F for 2 hr in the original container for the liquid bitumens, or at 200 F for 2 hr for the emulsified asphalt mixes.[2] After curing, the mixture is remixed by means of the spatula while cooling to room temperature, or until it has stiffened to the point that the bituminous coating will not flow off the stone to leave a thin coating. The coated aggregate is then submitted to water immersion.

(*b*) *Liquid Bitumens and Emulsified Asphalts—Wet Aggregate Test.*—To the dry aggregate is added a quantity of distilled water equal to 2 per cent by weight of the aggregate. The water and aggregate are vigorously mixed with the spatula until uniformly coated. To the wetted aggregate at room temperature, 5.5 ± 0.2 per cent of the liquid bitumen heated to the temperature described under Paragraph (*a*) above, is added and vigorously mixed with the spatula for 2 min. The subsequent operations are performed as under Paragraph (*a*).

For asphalt emulsions, this test is applicable only to the mixing type with the following modifications in procedure: Mixing shall be conducted with the aggregate at room temperature, and the mixture shall be cured at 200 F for 24 hr prior to water immersion.

(*c*) *Semi-Solid Bitumens.*—The test with semi-solid bitumens is performed with dry aggregate only. 100 g of the washed and dried aggregate are weighed into the tin container. The tin container with the aggregate is placed in a 275 to 300 F constant-temperature oven until the assembly attains this temperature (usually ½ to 1 hr). In the meantime the asphalt cement shall be heated separately to the same temperature as the aggregate. The heated container and aggregate are then balanced on scales on which a sheet of asbestos paper or other insulating material has been placed to retard chilling of the aggregate, and 5.5 ± 0.2 per cent of the heated bitumen added to the hot aggregate. The hot aggregate and bitumen are then mixed vigorously by means of the spatula whose blade has been previously warmed. The mixing is performed with the temperature of the ingredients being allowed to drop naturally and continued for 2 to 3 min, or until complete coverage of the surface of the aggregate is obtained. If complete coverage of the aggregate cannot be accomplished in the manner described, the mixture in the tin container is gently warmed on a hot-plate and the mixing continued until complete coating is obtained. In case the bitumen is in such a fluid state that it drains from the aggregate to leave a thin coating, the mixing is continued until the mixture becomes tacky. The asphalt coating on the aggregate must be complete, that is, no bare spots are permissible.

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[2] The ventilating ports on the oven should be open during this curing step.

After being satisfactorily coated, the bitumen-aggregate mixture is allowed to cool to room temperature and then, without further aging, subjected to water immersion.

Procedure

6. (*a*) *Water Immersion of Bitumen Coated Aggregate.*—Into a 600-ml. glass container, the coated aggregate, prepared as described in the preceding section, is placed and covered immediately with distilled water (6.0 to 7.0 pH) at room temperature, and 400 ml of distilled water are added. The coated aggregate is allowed to remain immersed in water for 16 to 24 hr (overnight). For stones coated with liquid bitumens, the water immersion is conducted at room temperature (77 F). For the semi-solid bitumens and the cured emulsified asphalts, the water immersion is conducted at 140 F, with the container covered with a watch-glass. At the end of the immersion period, the container and its contents are allowed to cool to room temperature.

(*b*) *Stripping Resistance Evaluation.*—Upon completion of the water immersion period, the stripping resistance shall be visually estimated as follows: Without further disturbance or agitation of the coated aggregate, and while still immersed in the water, the percentage of the area of the aggregate remaining coated is estimated visually. It is recommended that this estimation be made while the specimen is directly illuminated by a shaded lamp fitted with a 75-watt electric bulb, positioned to eliminate glare from the surface of the water. Any thin, brownish, translucent areas are to be considered fully coated.

APPENDIX III

COMPARATIVE TESTS ON CONCRETE JOINT SEALER, HOT-POURED, ELASTIC TYPE

TESTS MADE IN ACCORDANCE WITH THOSE SPECIFIED IN ASTM SPECIFICATIONS D 1190 – 52 T.[1]

Lot	Laboratory	Pour Point, deg Fahr	Safe Heating Temperature, deg Fahr	Cone Penetration, 77 F, 150 g, 5 sec	Flow at 140 F, cm	Bond Test, 5 cycles, 0 F; of 3 specimens, number passing
165	A	300	410+	83	0.1	3
	B	390	440	82	0.0	3
91	A	420	440+	71	0.1	3
	C	400	485	65	0.0	3
92	A	415	440+	71	0.1	3
	C	400	485	66	0.0	3
93	A	400	420+	74	0.0	3
	C	400	485	74	0.0	3
94	A	390	420+	71	0.0	3
	C	400	485	72	0.2	3
95	A	400	420+	69	0.0	3
	C	400	485	70	0.1	3
96	A	410	430+	66	0.0	3
	C	400	485	68	0.0	3
97	A	400	420+	66	0.0	3
	C	400	485	67	0.1	3
98	A	400	420+	68	0.0	3
	C	400	485	72	0.1	3
99	A	400	485	73	0.0	3
	C	400	420+	70	0.1	3
100	A	420	440+	65	0.0	3
	C	400	485	63	0.0	3
105	A	420	440+	66	0.0	3
	C	400	485	73	0.1	3
107	A	420	440+	67	0.0	3
	C	400	485	67	0.1	3
108	A	410	430+	63	0.0	3
	C	400	485	63	0.0	3
109	A	410	430+	65	0.0	3
	C	400	485	62	0.0	3
110	A	420	440+	66	0.0	3
	C	400	485	66	0.0	3
85	A	445	465+	58	0.0	3
	B	430	470+	59	0.0	3
96	A	445	465+	60	0.0	3
	B	430	470+	66	0.0	3
102	A	425	445+	85	0.1	3
	B	430	470+	83	0.0	3
197	A	400	420+	76	0.0	3
	B	400	470+	84	0.1	3
212	A	450	470+	55	0.0	3
	B	430	470+	61	0.0	3
170	A	375	395+	54	0.1	2
	B	380	410+	59	0.0	3
165	A	370	390+	74	0.1	3
	B	350	380+	82	0.0	3
415	A	405	425+	58	0.0	3
	B	400	440+	63	0.0	3
414	A	400	420+	55	0.0	3
	B	400	440+	63	0.0	3
580	A	420	440+	64	0.0	3
	B	400	440+	65	0.0	3
621	A	415	435+	63	0.0	2
	B	400	440+	66	0.0	3
447	A	420	440+	64	0.0	2
	B	400	440+	60	0.0	3
444	A	420	440+	56	0.0	2
	B	400	440+	62	0.0	3
Specification Requirement		At least 20 F below safe heating temperature	Not specified	90 max	0.5 max	2 min

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[1] 1952 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE D-5

ON

COAL AND COKE*

Committee D-5 on Coal and Coke held meetings in Atlantic City, N. J., on June 19, 1951, and in Cleveland, Ohio, on March 6, 1952. The Advisory Subcommittee held meetings on each of the above dates.

During the year four members were added to the committee and two members resigned, resulting in a total membership of 63, of whom 20 are classified as consumers, 18 as producers, and 25 as general interest members.

Chairman W. A. Selvig has continued his activity with the Classification Working Party, Coal Committee, and Economic Commission for Europe. He attended two meetings in Geneva, Switzerland during the year. Very satisfactory progress has been made in reaching agreement by the delegates on the basis of a scheme for classification of coal for international use.

In addition, Mr. Selvig attended, as an American delegate, the second meeting of Technical Committee 27 on Solid Mineral Fuels of the International Organization for Standardization (ISO) held in London December 10 to 14, 1951. This committee is engaged in the preparation of international standards for the sampling and analysis of coal.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. W. Anderson.
Vice-Chairman, C. C. Russell.
Secretary, O. P. Brysch.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Method of Sampling and Analysis of Coal for Volatile Matter Determination in Connection with Smoke Ordinances (D 980-48 T) be continued as tentative without revision during the coming year. Preliminary results of a survey currently being made by Subcommittee XIII on Coal Sampling (H. F. Hebley, chairman) indicate that this method has been used by municipalities with considerable satisfaction, so it is likely that the Society will be requested next year to adopt it as standard. The above investigation could not be completed in time for present committee recommendation.

STANDARDS CONTINUED WITHOUT REVISION

The following 14 standards have been published for six years or longer without revision. Except as noted in the subsequent summary of subcommittee activities, all are considered to be in accord with present practice. All are recommended for continuance in their present form with the understanding that work now in progress may in some cases result in early recommendations for revision:

Standard Specifications for:

Classification of Coals by Rank (D 388-38),
Classification of Coals by Grade (D 389-37),
Gas and Coking Coals (D 166-24),

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

Standard Methods of:

- Sampling and Fineness Test of Powdered Coal (D 197 - 30),
- Tumbler Test for Coal (D 411-45),
- Test for Screen Analysis of Coal (D 410 - 38),
- Designating the Size of Coal from its Screen Analysis (D 431 - 44),
- Test for Size of Anthracite (D 310 - 34),
- Test for Sieve Analysis of Crushed Bituminous Coal (D 311 - 30),
- Test for Cubic Foot Weight of Crushed Bituminous Coal (D 291 - 29),
- Test for Index of Dustiness of Coal and Coke (D 547 - 41),
- Sampling Coke for Analysis (D 346 - 35),
- Test for Volume of Cell Space of Lump Coke (D 167 - 24), and
- Test for Cubic Foot Weight of Coke (D 292 - 29).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Nomenclature and Definitions (A. W. Gauger, chairman) met on June 19, 1951, and agreed upon a definition for inherent moisture of coal. Since the definition inseparably relates to a method of determination, it has been referred to Subcommittee XXI on Methods of Analysis (O. W. Rees, chairman), which subcommittee is to prepare a standard procedure for determination of inherent moisture.

Subcommittee XIII on Coal Sampling (H. F. Hebley, chairman) met on March 5, 1952. The principal activity was an extensive sampling experiment at a large utility power plant in cooperation with a group representing the Edison Electric Institute. It is hoped eventually to formulate specifications for the continuous sampling of coal in large handling systems such as are found in most utility generating plants. Consideration given to the committee's present Tentative Method of Sampling and Analysis of Coal for Volatile Matter Determination in Connection with Smoke Ordinances (D 980 - 48 T) resulted in the institution of a use survey as previously discussed.

Subcommittee XV on Plasticity and Swelling of Coal (C. C. Russell, chairman) held no meetings during the year, but exchanges of information and data by mail were continued in the committee's investigation of the Gieseler test. This subcommittee has under study a revision of the Standard Method of Test for Free-Swelling Index of Coal (D 720 - 46).

Subcommittee XVII on Significance of Tests of Coal and Coke (N. Isenberg, chairman). A Section on Combustion of this subcommittee completed its assignment, and J. F. Barkley, chairman of the Combustion Section edited the resulting papers which have been published as Bureau of Mines *I.C. 7619*, "Significance of Laboratory Tests of Coal and Coke for Combustion." The Bureau reports great interest in the publication, with 1400 copies already distributed.

Subcommittee XXI on Methods of Analysis (O. W. Rees, chairman) met on October 29, 1951, and ironed out many details in the proposed revision of the procedures for the ultimate analysis of coal and coke. This subcommittee currently has the largest back-log of work of any group under Committee D - 5, and chairman Rees has recently effected a reorganization into three sections which are to consider, respectively, matters pertaining to proximate, ultimate, and miscellaneous analytical procedures.

In addition to the activities just outlined, a complete review of all Committee D-5 sponsored tests dealing with the physical characteristics of coke is to be undertaken. A new Subcommittee on the Physical Tests of Coke is being organized under the chairmanship of B. P. Mulcahy.

This report has been submitted to letter ballot of the committee, which consists of 61 members; 48 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. A. SELVIG,
Chairman.

C. H. SAWYER,
Secretary.

REPORT OF COMMITTEE D-6
ON
PAPER AND PAPER PRODUCTS*

Committee D-6 on Paper and Paper Products held two meetings during the year: on June 21, 1951, at Atlantic City, N. J., and on February 22, 1952, at New York, N. Y. The Advisory and other subcommittees held meetings on the same dates.

At the present time, Committee D-6 consists of 87 members, of whom 75 are voting members; 26 are classified as producers, 27 as consumers, and 34 as general interest members.

An editorial task group was established to review existing test methods in order to establish a definite pattern to be followed in writing new methods and revising existing ones.

The new edition of the Monograph on Paper and Paperboard; Characteristics, Nomenclature, and Significance of Tests has been completed and published as STP 60-A. Paragraphs on significance will be prepared for inclusion in all of the test methods.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. R. Willets.
Vice-Chairman, T. J. Gross.
Secretary, R. H. Carter.

NEW TENTATIVES

The committee recommends that the following five methods be accepted for publication as tentative, as appended hereto:[1]

Tentative Methods of Test for:

Pinholes in Glassine and Other Greaseproof Papers,
Zinc and Cadmium in Paper,
Contrast Gloss of Paper at 57.5 Deg,
Specular Gloss of Paper at 75 Deg, and
Flat Crush of Corrugated Paperboard.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following five tentatives be approved without revision for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for:

Organic Nitrogen in Paper and Paperboard (D 982 - 50 T),[2]
Peeling Resistance of Paperboard (D 1029 - 50 T),[2]
Static Bending Test for Corrugated Paperboard (D 1098 - 50 T),[2] and
Water-Soluble Sulfates in Paper and Paperboard (D 1099 - 50 T).[2]

Tentative Specifications for:

Filter Paper for Chemical Analysis (D 1100 - 50 T).[2]

TENTATIVE REVISION OF STANDARDS

The committee recommends revision of the following two standards for publication, as appended hereto.[3] It is planned that these complete revisions will replace the existing standards when they are adopted as standard:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 7.

[2] 1950 Supplement to Book of ASTM Standards, Part 4.

[3] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 7.

Standard Methods of Test for:

Ply Adhesion of Paper or Vulcanized Fibre (D 825 – 48),[4] and
Time of Penetration by Water of Sized Paper and Paper Products (Dry Indicator Method) (D 779 – 46).[4]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following three tentative methods which have stood for two years without revision be continued as tentative:

Tentative Method of Test for:

Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard (D 781 – 44 T),
Stretch of Paper and Paper Products under Tension (D 987 – 48 T), and
Fiber Analysis of Paper and Paperboard (D 1030 – 49 T).

A revision of Method D 781 is under consideration with round-robin testing being done at this time. A possible modification of the method for stretch to adapt it to creped paper is under study and the Methods for Fiber Analysis is being reviewed for possible revision.

REAFFIRMATION OF STANDARDS

The committee recommends that the following standards, which have stood for six years without revision, be reaffirmed and continued as such:

Standard Methods of Test for:

Rosin in Paper and Paperboard (D 549 – 46),
Opacity of Paper and Paper Products (D 589 – 44),
Internal Tearing Resistance of Paper (D 689 – 44),
Degree of Staining of Paper by Alkali (D 723 – 45),
Surface Wettability of Paper (Angle-of-Contact Method) (D 724 – 45),
Kerosine Number of Roofing and Flooring Felt by the Vacuum Method (D 727 – 45),
Effect of Heating on Folding Endurance of Paper (D 776 – 46),
Flammability of Treated Paper and Paperboard (D 777 – 46), and
Printing Ink Permeation of Paper (Castor Oil Test) (D 780 – 46).

The remaining standard methods which have stood for six years are in the process of revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I, on Paper Testing Methods (R. H. Lace, chairman) has been active in developing new methods of test, and has also continued its critical study of various methods of test for paper and paper products that have been adopted by other agencies such as the Technical Association of the Pulp and Paper Industry. The subcommittee prepared four of the new test methods which are recommended for publication as tentative earlier in this report. Two of the tentative methods being recommended for adoption as standard (D 982 and D 1099), the two tentative revisions, and all of the reaffirmed standards are also under the jurisdiction of this subcommittee.

Test methods to determine light fastness, moisture expansivity, and erasability are being developed. Studies are also being made which may lead to proposed revisions in Standard Method of Conditioning Paper and Paper Products for Testing (D 685 – 44), Bursting Strength of Paper (D 774 – 46), Wet Tensile Breaking Strength of Paper and

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[4] 1949 Book of ASTM Standards, Part 4.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Paper Products (D 829 – 48), Resistance of Paper to Passage of Air (D 726 – 48), Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 – 44), Turpentine Test or Grease Resistance of Paper (D 722 – 45), Sampling Paper and Paper Products (D 585 – 42), Basic Weight of Paper and Paper Products (D 646 – 50), and Tensile Breaking Strength of Paper and Paper Products (D 828 – 48).

Subcommittee II, on Significance of Test Methods (L. S. Reid, chairman) completed the revision of the Monograph on Paper and Paperboard; Characteristics, Nomenclature, and Significance and now will prepare significance paragraphs for inclusion in all of the methods.

Subcommittee IV, on Container Board (W. B. Lincoln, Jr., chairman) prepared one of the new test methods being recommended for publication as tentative, namely, Flat Crush of Corrugated Paperboard. Tentative Methods D 1029 – 50 T and D 1098 – 50 T, which are being recommended for adoption as standard, are also under the jurisdiction of this subcommittee.

The subcommittee is currently working on procedures for determination of immersion number and wet bursting strength. Studies are also being made which may result in proposed revision of the Standard Method of Sampling Paper and Paper Products (D 585 – 42).

This report has been submitted to letter ballot of the committee, which consists of 75 voting members; 50 members returned their ballots, of whom 37 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. R. WILLETS,
Chairman.

R. H. CARTER,
Secretary.

REPORT OF COMMITTEE D-7

ON

WOOD[*]

Committee D-7 on Wood met in Chicago, Ill., on March 11, 1952. On March 10 meetings of Subcommittee I on Specifications for Timber and Subcommittee IX on Methods of Testing were held.

In recognition of the increased production of, and stimulated interest in, fiberboards, a new subcommittee, designated Subcommittee XV on Structural Fiberboard, was organized, with Wayne C. Lewis as chairman.

No meetings of ISO Committee TC55—Timber (Sizing, Defects), or of ASA Sectional Committee O5 on Specifications for Wood Poles, on which Committee D-7 is to be represented, were held during the year.

Action was initiated during the year to disband ASA Sectional Committee O4 on Methods of Testing Wood, through concurrence of the joint sponsors, U. S. Forest Service and ASTM, and the committee membership. ASTM standards would then be presented to the ASA for adoption through the proprietary standards method, without the need of maintaining the organization of a separate sectional committee.

The election of officers for the ensuing term of two years resulted in selection of the following:

Chairman, L. J. Markwardt.
Secretary, L. W. Smith.

Adoption of Tentatives as Standard

The committee recommends that the Tentative Nomenclature of Domestic Hardwoods and Softwoods (**D 1165 – 51 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard. The committee at the same time is making a few editorial changes in view of certain changes in terminology that have been made by the Tree Name Committee of the Department of Agriculture.

The committee also recommends that the Tentative Definitions Relating to Veneer and Plywood (**D 1038 – 49 T**)[1a] be approved for reference to letter ballot of the Society for adoption as standard with the following changes:

Revise the following four definitions:

Bleed Through.—Glue or components of glue that have seeped through the outer layer or ply of a glued wood product and that show as a blemish or discoloration on the surface.

Center.—See Core.

Compregnated Wood (*Compreg*).—Synthetic resin-treated, compressed wood with reduced swelling and shrinking characteristics and increased density and strength properties.

Construction. — Arrangement of veneers or lumber in the fabrication of plywood.

All - Veneer Construction. — Plywood in which all plies are of veneer. Ordinarily no single ply of veneer will exceed $\frac{5}{16}$ in. in thickness.

Durability.—As applied to wood, its lasting qualities or permanence in service with particular reference to decay. May be related directly to an exposure condition. (See also Delamination.)

Delete the definition of flexwood which reads as follows:

Flexwood.—A trade name describing cloth-backed thin veneer for interior walls, especially plaster and masonry.

Add the following two new definitions:

Sunken Joint.—In the case of plywood a depression in the surface of the face ply directly above an edge joint in a lumber core or cross band. Usually the result of localized shrinkage in the edge-jointed layer. (Sunken joints may also be present in edge-laminated lumber.)

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[*] Presented at the Fifty-fifth Annual Meeting of the Society, June 17-23, 1952.

[1] 1951 Supplement to Book of ASTM Standards, Part 4.

[1a] 1949 Book of ASTM Standards, Part 4.

Striated.—A term used to describe plywood with a face veneer that has been grooved or scored parallel to the grain.

REVISION OF TENTATIVE

The committee recommends that the Tentative Methods of Test for Evaluating the Properties of Fiber Building Boards (**D 1037 – 49 T**), be revised as appended hereto[2] and continued as tentative.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specifications for Round Timber Piles (**D 25 – 37**) be revised as appended hereto[3] and reverted to tentative.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the following two methods, as appended hereto,[2] and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Methods of Testing:

Small Clear Specimens of Timber (D 143 – 50), and

Plywood, Veneer, and Other Wood and Wood-Base Materials (D 805 – 47).

STANDARDS AND TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following standards and tentatives be continued in their present status without revision pending further study:

Standard Specifications for:

Wooden Paving Blocks for Exposed Pavements (D 52 – 20),

Standard Methods of:

Sampling and Testing Creosote (D 38 – 33),
Static Tests of Timbers in Structural Sizes (D 198 – 27),

Standard Method of Test for:

Tar Acids in Creosote and Creosote-Coal Tar Solutions (D 453 – 41),
Coke Residue of Creosote (D 168 – 30),
Specific Gravity of Creosote (D 368 – 33),
Specific Gravity, 38/15.5 C, of Creosote Fractions (D 369 – 33),
Water in Creosote (D 370 – 33),
Standard Volume and Specific Gravity Correction Tables for Creosote and Coal Tar (D 347 – 33),

Standard Definition of Terms Relating to:

Timber (D 9 – 30),
Timber Preservations (D 324 – 41),

Tentative Specifications for:

Creosoted End-Grain Wood Block Flooring for Interior Use (D 1031 – 49 T),

Tentative Methods of:

Static Tests of Wood Poles (D 1036 – 49 T),
Establishing Structural Grades of Lumber (D 245 – 49 T),

Tentative Method of Test for:

Integrity of Glue Joints in Laminated Wood Products for Exterior Service (D 1101 – 50 T),
Ash in Wood (D 1102 – 50 T),
Alpha-Cellulose in Cellulosic Materials (D 1103 – 50 T),
Holocellulose in Wood (D 1104 – 50 T),
Preparation of Extraction-Free Wood (D 1105 – 50 T),
Lignin in Wood (D 1106 – 50 T),
Alcohol-Benzene Solubility of Wood (D 1107 – 50 T),
Ether Solubility of Wood (D 1108 – 50 T),
One Per Cent Caustic Soda Solubility of Wood (D 1109 – 50 T), and
Water Solubility of Wood (D 1110 – 50 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I, on Specifications for Timber (Lyman W. Wood, chairman).—The revision of Standard Specifications for Round Timber Piles (D 25 – 37) has been completed and recommended for reversion to tentative status as noted earlier in this report. Research studies are continuing on basic principles of structural grading. The results of these studies will be included in the pending revision of Tentative Methods for Establishing Structural Grades of Lumber (D 245 – 49 T).

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[2] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 4.

[3] The revised specifications were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 4.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee II, on Laminated Timber (F. J. Hanrahan, chairman).— No changes are contemplated at present in Tentative Method of Test for Integrity of Glue Joints in Laminated Wood Products for Exterior Service (D 1101 – 50 T). However, because of continuing studies in this field there is a possibility some revision may become desirable during the coming year.

Subcommittee III, on Plywood (J. A. Liska, chairman).—Subcommittee III has reviewed Tentative Definitions of Terms Relating to Veneer and Plywood (D 1038 – 49 T) and has recommended a number of revisions which will, it is believed, improve the definitions. The revision is recommended for adoption as standard, as noted earlier in this report.

Subcommittee IV, on Wood Paving Blocks (W. H. O'Brien, chairman).— The Specifications for Creosoted End-Grain Wood Block Flooring for Interior Use (D 1031 – 51) under the jurisdiction of the subcommittee were advanced to standard in 1951. The standard will be reviewed during the coming year from the standpoint of possible need of minor revision.

Subcommittee VI, on Timber Preservatives (R. H. Bescher, chairman).—No specific recommendations for changes in the present specifications for preservatives are being made, and no new specifications have been prepared, because all specifications for preservatives are in a state of flux at this time. It is believed that the situation will be somewhat clarified in the near future. In the meanwhile, the subcommittee will continue the study of distillate specifications for creosote, specifications for non-standard preservatives, and specifications for creosote and creosote coal-tar solutions. A small sectional committee has been appointed to study soluble tests, other than benzol tests for creosote and creosote coal-tar solutions. The subcommittee hopes to have information available for a report next year.

Subcommittee VIII, on Modified Wood and Wood-Base Material (W. G. Youngquist, chairman).—Revisions of Standard Methods of Testing Plywood, Veneer and Other Wood and Wood-base Materials (D 805 – 47) now in progress include improved details of test for modified woods. During the coming year consideration will be given to the preparation of the supplementary specifications for modified wood which will include definitions of terms and the ranges in physical and mechanical properties of the most commonly used modified woods.

Subcommittee IX, on Methods of Testing (L. J. Markwardt, chairman).— Extensive work has been under way on methods of test during the past year, including a discussion of methods at an international conference of the FAO in Europe in August, 1951. As a result of these developments revisions have been recommended on three of the methods of test under the jurisdiction of Committee D-7, namely, Methods of Test for Evaluating the Properties of Fiber Building Boards (D 1037 – 49 T), Standard Methods of Testing Veneer, Plywood, and Other Wood and Wood-base Materials (D 805 – 47), and Standard Methods of Testing Small Clear Specimens of Timber (D 143 – 50).

The principal revisions recommended for D 1037 – 49 T include the addition of a hardness test method, recommendation for the use of a dial comparator of special design for measuring linear variation with change in moisture content, the unification of the requirement for accuracy of measurements, the establishment of unified temperature requirements for conditioning and testing, and the inclusion of equivalent metric units.

The principal revisions recommended for D 805 – 47 consist of including a simple compression specimen without lateral support for use in evaluating the maximum compressive strength, the addition of two alternate tension specimens for use when maximum tensile strength only is required, the adoption of standard temperature and humidity requirements for conditioning and testing material, and the inclusion of equivalent metric units.

The principal change recommended for (D 143 – 50) was the adoption of a new form of tension parallel-to-grain specimen.

Subcommittee X, on Nomenclature and Definitions (R. R. Cahal, chairman).—The Tentative Nomenclature of Domestic Hardwoods and Softwoods (D 1165 – 51 T) was presented for adoption as standard. This nomenclature was formerly included with "Standard Names for Structural Timbers" in D 9 – 30. The separation of nomenclature from the original standard represents a change in the treatment of the subject which is regarded as being timely and fully justified.

Subcommittee XI, on Moisture Content of Timber (M. E. Dunlap, chairman).—A new machine has recently been placed in use for classifying moving lumber according to moisture content. It is reported that the machine will mark or discard boards of irregular moisture content as they pass in a conveyor system or dry chain. So far as is known by the subcommittee, this is the first machine of this kind that is to be produced for general use.

Subcommittee XII, on Fire-Retardant Wood (W. H. Fulweiler, chairman).—There are still many problems concerning the interpretation of data relating to fire tests. Because of the complications it will be some time before any specific recommendations will be forthcoming. Work has been under way in the development of a small scale tunnel fire test which, when completed, may have some bearing on the work of this subcommittee.

The subcommittee is working on a new method of acceptance testing to get away from performance tests by means of specifications for retention and penetration of fire retardants. Consideration is being given to the evaluation of retention in treated material based on surface area instead of volume.

Subcommittee XIV, on Methods of Chemical Analysis (G. J. Ritter, chairman).—During the year Subcommittee XIV completed the eleventh of a series of methods of chemical analysis by finishing an evaluation of the method of analysis of methoxyl in wood.

In addition, a survey was made of methods for quantitative determination of iron, manganese, phosphorus, calcium, and magnesium in wood. As a result of the survey it seems that some modifications of the methods examined will be desirable in order to make them applicable to the various types of wood specimens used in commercial practice. It is hoped that time will be available for making the modifications during the coming year.

This report has been submitted to letter ballot of the committee, which consists of 79 voting members; 36 members returned their ballots, of whom 35 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. J. MARKWARDT,
Chairman.

L. W. SMITH,
Secretary.

REPORT OF COMMITTEE D-8
ON
BITUMINOUS WATERPROOFING AND ROOFING MATERIALS*

Committee D-8 on Bituminous Waterproofing and Roofing Materials held two meetings during the year; one in Atlantic City, N. J. on June 20, 1951, the other in Cleveland, Ohio on March 5, 1952.

The committee suffered the loss of two members, J. E. Myers and Charles A. Mayer, through resignation.

The committee also suffered the loss through death of E. H. Berger who died on May 13, 1952.

The membership consists of 75 voting members, composed of 45 producers, 11 consumers, and 19 general interest members.

All of the standards and tentatives for which Committee D-8 is responsible have been studied, and the recommendations are set forth in this report.

NEW TENTATIVES

Committee D-8 recommends that the following proposed tentatives as appended hereto be accepted for publication as tentative:[1]

Proposed Tentative Specifications for Asphalt Insulating Siding Surfaced with Mineral Granules,
Proposed Tentative Specifications for Asphalt-Base Emulsion for Use as Protective Coatings for Built-Up Roofs, and
Proposed Tentative Method for Testing Asphalt Insulating Siding Surfaced with Mineral Granules.

ADOPTION OF TENTATIVE AS STANDARD

Specifications for Asphalt Roofing Surfaced with Powdered Talc or Mica (**D224 - 50 T**).—The committee recommends that these specifications be approved for reference to letter ballot of the Society for adoption as standard.

REVISION OF TENTATIVE

Committee D-8 recommends the revision of the *Tentative Definitions of Terms Relating to Bituminous Waterproofing and Roofing Materials* (**D 1079 - 50 T**)[2] by the addition of the following terms:

Waterproofing.—Treatment of a surface or structure which prevents the passage of liquid water.

Dampproofing.—Treatment of a surface or structure which retards the passage of liquid water.

Committee D-8 recommends the revision of the Tentative Methods of Sampling Bituminous Materials (D 140 - 49 T) as appended hereto.[3] This tentative is under the joint jurisdiction of Committees D-4 and D-8, and both committees have agreed upon this recommendation.

EDITORIAL CHANGES

The committee recommends the following editorial changes in these specifications:

Tentative Specifications for Asphalt Roofing Surfaced with Powdered Talc or

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

[2] 1950 Supplement to Book of ASTM Standards, Part 3.

[3] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 3.

Mica (**D 224 - 50 T**)[2] and *Tentative Specifications for Asphalt Roofing Surfaced with Mineral Granules* (**D 249 - 50 T**).[2]

Table I.—Eliminate the words "Mineral Stabilized" before the word "coating" in the line designating the weight of coating per 108 square feet.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following 12 standards:

Standard Specifications for:

Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 44),
Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 - 47),
Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 47),
Asphalt-Saturated Abestos Felts for Use in Waterproofing and Constructing Built-Up Roofs (D 250 - 47),
Asphalt for Use in Constructing Built-Up Roof Coverings (D 312 - 44),
Asphalt for Dampproofing and Waterproofing (D 449 - 49),
Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 49), and
Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 - 47).

Standard Methods of:

Sampling and Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (D 146 - 47),
Testing Films Deposited from Bituminous Emulsions (D 466 - 42),
Testing Emulsified Asphalts (D 244 - 49), and
Standard Volume Correction Table for Tar and Coal Tar Pitch (D 633 - 44).

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-8 recommends that the following tentatives, which have been published by the Society for two or more years, be continued without revision since they are being reviewed for possible revisions to be recommended before the next Annual Meeting:

Tentative Recommended Practice for Accelerated Weathering Test of Bituminous Materials (D 529 - 39 T),
Tentative Methods of Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 - 48 T), and
Tentative Specifications for Asphalt Roofing Surfaced with Mineral Granules (D 249 - 50 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. R. Snoke.
Vice Chairman, H. W. Greider.
Secretary, G. W. Robbins.

This report has been submitted to letter ballot of the Committee, which consists of 75 members; 46 members have returned their ballots, all of whom have voted affirmatively.

Respectfully submitted in behalf of the committee,

A. J. STEINER,
Chairman.

G. W. ROBBINS,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE D-9

ON

ELECTRICAL INSULATING MATERIALS*

Committee D-9 on Electrical Insulating Materials held two meetings during the year: in Niagara Falls, Ontario, on November 14 to 16, 1951, and in Philadelphia, Pa. on February 27 to 29, 1952.

At these meetings action was taken on several new methods, new recommended practices, revisions of existing tentatives, and changes in some of the standards under the jurisdiction of Committee D-9. Also progress was made on other projects under study by the various subcommittees as mentioned later in the report.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. H. Scott.
Vice-Chairman, W. A. Zinzow.
Recording Secretary, B. E. Ely.
Membership Secretary, A. J. Balch.

At its meeting on February 29, Committee D-9 unanimously elected the following as Honorary Members of the Committee: H. L. Curtis, M. P. Davis, Dean Harvey, and E. A. Snyder, in appreciation of their long-time service and many contributions to the work of the committee.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 51 T) be revised. This recommendation was accepted by the Standards Committee on November 30, 1951, and the revised methods appear in the 1951 Supplement to Book of ASTM Standards, Part 6, as well as in the current Compilation of ASTM Standards on Electrical Insulating Materials.

The following recommendations submitted by Committee D-9 were accepted by the Standards Committee on February 15, 1952:

Tentative Method of:

Test for Insulation Resistivity of Electrical Insulating Oils of Petroleum Origin (D 1169 – 52 T).

Revision of Tentative Specifications for:

Natural Muscovite Mica Based on Visual Quality (D 351 – 49 T),
Laminated Thermosetting Materials (D 709 – 49 T), replacing Specifications D 467 and D 616, and
Vulcanized Fibre Sheets, Rods, and Tubes Used for Electrical Insulation (D 710 – 49 T).

Revision of Tentative Methods of:

Testing Varnishes Used for Electrical Insulation (D 115 – 51 T),
Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 50 T),
Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 51 T),
Testing Vulcanized Fibre Used for Electrical Insulation (D 619 – 49 T), and
Testing Varnished Glass Fabrics and Varnished Glass Fabric Tapes Used in Electrical Insulation (D 902 – 50 T).

Tentative Revision of Standard Method of:

Test for Power Factor and Dielectric Constant of Electrical Insulating Oils of Petroleum Origin (D 924 – 49), and

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Test for Power Factor and Dielectric Constant of Natural Mica (D 1082 – 51).

Revision and Reversion to Tentative of Standard Specifications for:

Natural Block Mica and Mica Films Suitable for Use in Fixed Mica Dielectric Capacitors (D 748 – 49).

Withdrawal of Tentative Specifications for:

Phenolic Laminated Sheet for Radio Applications (D 467 – 44 T), and

Round Phenolic Laminated Tubing for Radio Applications (D 616 – 41 T).

The new and revised tentatives as well as the tentative revisions appear in the current Compilation of ASTM Standards on Electrical Insulating Materials.

The following further recommendations of Committee D-9 were submitted to the Administrative Committee on Standards subsequent to the 1951 Annual Meeting:

Tentative Specifications for:

Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 – 52 T), replacing Standards D 760 and D 761, and

Cellulose Acetate Sheet and Film for Primary Insulation (D 1202 – 52 T).

Revision of Tentative Methods of:

Molded Materials Used for Electrical Insulation (D 48 – 46 T), and

Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 52 T).

Withdrawal of Standard Specifications for:

Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 – 49), and

Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 – 49).

The revision of Methods D 48 was accepted by the Standards Committee on April 4, 1952; the remaining recommendations were accepted on April 2, 1952. With the exception of D 1202 – 52 T, the new and revised tentatives appear in the current Compilation of ASTM Standards on Electrical Insulating Materials.

RECOMMENDATIONS AFFECTING STANDARDS

As a result of the year's work, the committee is submitting revisions of five tentatives, the adoption of four tentative revisions of standards, the adoption of one tentative as standard, the withdrawal of one standard, and the reaffirmation of nine standards. The standards and tentatives affected, together with the recommended revisions, are presented in detail in the Appendix to this report.

These recommendations have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (A. H. Haroldson, chairman).—Sections A and B of this subcommittee have cooperated in rewriting the Tentative Methods of Testing Varnishes Used for Electrical Insulation (D 115 – 51 T). The test methods have been classified either as control or performance tests. The control tests are intended to be used as a guide for uniformity and identification, and the performance tests to determine the performance of the varnish for application work. The test temperature of 25 C has been changed to 23 ± 1.1 C to conform to ASTM Standards.

A definition for casting resins used for potting and embedding purposes has been added to the revised Methods D 115. There has been some question concerning the validity of classifying casting resins as varnishes, since the liquid component is both a solvent and a resin constituent which, under suitable conditions, will copolymerize with another resin constituent without appreciable loss of weight. Since the present methods do not include a definition for insulating varnishes, it was decided that before a definite decision can be reached it would be necessary to define electrical insulating varnishes on the basis of composition and use. Section A has been assigned the problem of drafting this definition.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Four methods which are being used in the industry for the determination of set time have been studied in a round-robin testing program by Section C on Laminating Varnishes. Different laboratories using the same method did not obtain check results. The test results indicate the necessity for standardization of the oil bath equipment. It was decided that before further tests are conducted the equipment should be standardized. The standard oil bath equipment will consist of a 2-liter stainless steel beaker with a rolled flange at the top. The beaker will be enclosed in an electric heating mantle equipped with proper control for maintaining a constant temperature. The beaker will be equipped with an asbestos and metal cover containing holes of the required size to accommodate the test tube and thermometer. The thermometer will be standardized against a Bureau of Standards thermometer. Fisher wax will be used for the bath. Plans have been made to conduct additional round-robin tests using the standardized equipment.

Arrangements have been made by Section D on Silicone Varnishes to start round-robin tests on silicone varnishes. The tests will include dielectric strength, time of drying, and draining test. Test methods for heat aging, heat stability, oil resistance, weight loss, adhesion, cold checking, water resistance (tap and salt water), and water content will be considered at a later date with the cooperation of Section H on Oil Resistance. Heat flexibility and heat stability will be studied with the aid of the method for determining the effect of elevated temperature on the dielectric strength of silicone-coated fiberglass fabric developed by Subcommittee VII. The samples will be subjected to 250 and 275 C for various periods of time and the following tests conducted: weight loss, dielectric strength, and dielectric strength after bending.

Subcommittee III on Plates, Rods, Tubes, and Molded Materials (G. H. Mains, chairman).—A revision of the Tentative Specifications for Phenolic Molding Compounds (D 700 – 49 T) providing for changes in the definition of various grades, and in the values of a number of the properties for some of these grades is being submitted to subcommittee letter ballot.[2] Further work is under way to correlate the new Tentative Specifications for Cellulose Acetate Sheet and Film for Primary Insulation (D 1202 – 52 T)[3] with the Military Specification MIL-I-631.

This subcommittee is cooperating with Subcommittee I on Strength Properties, of Committee D-20 on Plastics, on various mechanical tests. A round-robin test has been conducted on improved methods of testing flexural strength of laminates, and a statistical analysis of the data is being studied. Assistance has also been given to Committee D-20 on Plastics on a revision of the Tentative Method of Test for Compressive Strength of Plastics (D 695 – 49 T), and based on this work changes will be made in the D-9 Methods D 229, D 348, and D 349.

Work on a revision of Method D 669 – 42 T covering dissipation factor measurements parallel to laminations is progressing, including the round-robin test on a suggested improvement.

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[2] See Editorial Note, p. 429.

[3] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 6.

A revision of the Method of Testing Non-Rigid Polyvinyl Tubing (D 876 - 51 T) to provide new conditioning procedures for dielectric strength tests is being submitted to subcommittee letter ballot,[4] as is also a revision of the Specifications for Non-Rigid Polyvinyl Tubing (D 922 - 47 T) involving dielectric strength and stress-relief values.[4]

Subcommittee IV on Liquid Insulation (F. M. Clark, chairman).—Among the more active problems which have been investigated by Subcommittee IV during the past year are those dealing with the sludge evaluation of inhibited and uninhibited oils, the dielectric strength testing of oils, the evaluation of combined but corrosive sulfur in oil, and the determination of dissolved water in oil. Other projects which are under consideration include the problem of screening specification requirements, the interfacial tension test for oils in service, the establishment of an improved steam emulsion testing procedure, and the testing methods associated with the acceptance and use of the askarels.

The activities of the subcommittee have been ably directed by Mr. E. A. Snyder for over a quarter of a century. During the year Mr. Snyder's resignation from the responsibilities of the chairmanship of the subcommittee was accepted with regret and he was elected an Honorary Member of Subcommittee IV. The subcommittee is fortunate that Mr. Snyder is remaining as an active member and will continue to participate in its activities.

Subcommittee VIII on Insulating Papers (C. E. Peterson, chairman) took action during the year to add a test method for dielectric strength of untreated insulating paper to Methods D 202. Significance statements on the following tests were also added to Methods D 202: alcohol soluble matter, water soluble matter, water extraction conductivity, and fiber analysis. Letter ballots are in progress on a revision of the Tentative Specifications for Absorbent Laminating Paper for Electrical Insulation (D 1080 - 49 T), and on the approval of the Tentative Method of Test for Water Soluble Matter In Paper (D 1162 - 51 T) as a replacement for the test in Methods D 202. Jurisdiction of the Standard Method of Test for Thickness of Solid Electrical Insulation (D 374) has been transferred to Subcommittee 16 on Thickness Measurements, of Committee E-1 on Methods of Testing. The several sections are giving consideration to other projects, as follows:

Section A (J. I. Adams, chairman) to refinement of various chemical methods and the development of a suitable method for determination of soluble chlorides at concentrations on the order of 10 parts per million.

Section B (E. G. Ham, chairman) to investigation pertaining to dielectric strength of untreated insulating papers and methods of evaluating formation.

Section C (P. F. Wehmer, chairman) to elongation of creped insulating papers and bursting strength at more than 200 psi.

Section E (J. H. Palmer, chairman) to significant statements for test methods.

Section F (H. A. Anderson, chairman) to specifications for interlayer insulating paper. Specifications for interlayer paper are making progress and it is anticipated that capacitor paper will be considered next.

Subcommittee IX on Mica (E. O. Hausmann, chairman) is working actively through the American Standards Association with Technical Committee 56 on Mica, of the International Organization for Standardization, in the development of international standards for raw mica.

During the year revisions were completed and presented to the Society in the following standards for mica: Specifications D 748, and Methods D 351 and D 1082, as mentioned earler in this report.

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[4] The revised tentative was accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 6.

The subcommittee has under way a round-robin test program for the purpose of verifying the calibration of the new parallel-to-laminations technique in Method B, Appendix I, of the Tentative Specifications for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 - 52 T). The new parallel-to-laminations test method is an extension of the rapid, direct-reading test method for determining Q value of mica in the 1949 edition of D 748, and is particularly suitable for evaluating and controlling dielectric loss of individual mica films, whereas the original perpendicular-to-laminations test method was better suited for testing block mica.

Subcommittee XI on Significance of Tests (J. H. Palmer, chairman) has proposed recommendations covering the positioning of significant statements with regard to the test methods prepared by Committee D-9.

Subcommittee XII on Electrical Tests (K. N. Mathes, chairman) completed revisions of the Tentative Methods of Test for Electrical Resistance of Insulating Materials (D 257 - 49 T) and the Tentative Methods of Test for Power Factor and Dielectric Constant (D 150 - 47 T).

The following sections in the subcommittee were renamed: Section A from Resistivity Method, to Resistivity; Section C from Power Factor of Solid Insulation, to Dielectric Loss Characteristics; and Section E from Measurement of Dielectric Strength, to Dielectric Strength.

Section B on Power Factor of Liquid Insulation was dissolved, with its responsibilities divided between Sections C and H.

A Panel Discussion on Insulation Resistance Testing was held at the spring meeting, with Mr. I. Easton as moderator. The members of the panel were successful in producing a very interesting program which was appreciated by a large audience.

This report has been submitted to letter ballot of the committee which consists of 173 members; 88 members returned their ballots, of whom 77 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. H. SCOTT,
Chairman.
W. A. ZINZOW,
Vice-Chairman.

M. GUARNIER,
Recording Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Methods of:

Testing Varnishes Used for Electrical Insulation (D 115 - 51 T), and
Testing Nonrigid Polyvinyl Tubing (D 876 - 51 T).

Revision of Tentative Specifications for:

Nonrigid Polyvinyl Tubing (D 922 - 47 T), and
Phenolic Molding Compounds (D 700 - 49 T).*

These recommendations were accepted by the Standards Committee on December 12, 1952, and the revised methods and specifications appear in the 1952 Book of ASTM Standards, Part 6.

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* Jointly with Committee D-20 on Plastics.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRICAL INSULATING MATERIALS

In this Appendix are given recommendations affecting certain standards and tentatives concerning electrical insulating materials which are referred to earlier in this report. The standards and tentatives appear in their present form in the 1949 Book of ASTM Standards, Part 6, and its 1950 and 1951 Supplements, as indicated by the final number in the ASTM designation.

Revisions of Tentatives

Tentative Specifications for Orange Shellac and Other Indian Lacs for Electrical Insulation (D 784 – 50 T):

Table I.—Change the test temperature for the flow test of shellac from "110 ± 1 C" to read "100 ± 1 C."

Standard Methods of Testing Shellac Used for Electrical Insulation (D 411 – 50 T):

Section 9 (*a*).—In the third and eighth lines, change the temperature for the flow test from "110 ± 1 C" to read "100 ± 1 C."

Section 12 (*b*).—In the last line, change the test temperature from "110 ± 1 C" to read "100 ± 1 C."

Tentative Methods of Testing Askarels (D 901 – 50 T):

Sections 2 to 8.—For these sections substitute the revised sampling procedure appended hereto.[1]

Tentative Specifications for Absorbent Laminating Paper for Electrical Insulation (D 1080 – 49 T):

Tables II, III, and IV.—Revise the chemical, physical, and dimensional requirements as shown in the accompanying Table I.

Tentative Methods of Test for Electrical Resistance of Insulating Materials (D 257 – 49 T):

The committee recommends that these methods be revised as appended hereto.[1]

Adoption of Tentative Revisions as Standard

The committee recommends the adoption as standard of the tentative revisions in the following standards and requests that they be approved for reference to letter ballot of the Society:

Standard Methods of Testing Laminated Tubes Used for Electrical Insulation (D 348 – 46), revision of Sections 4 and 5 and Fig. 1.[2]

Standard Methods of Testing Laminated Round Rods Used for Electrical Insulation (D 349 – 46), revision of Section 4 and Fig. 1.[2]

Standard Methods of Measuring Dimensions of Rigid Tubes Used in Electrical Insulation (D 668 – 44), revision of Sections 6, 7, 8, 10 and 11.[2]

Standard Methods of Testing Pasted Mica Used in Electrical Insulation (D 352 – 49), revision of Sections 2, 3, 8, 9, 15, 16, 22, 23, 29, 30 and 33.[3]

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[1] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 6.

[2] 1949 Book of ASTM Standards, Part 6.

[3] 1951 Supplement to Book of ASTM Standards, Part 6.

TABLE I.—REVISED CHEMICAL, PHYSICAL, AND DIMENSIONAL REQUIREMENTS.

CHEMICAL REQUIREMENTS

	Type	Minimum	Maximum
Moisture, as received, per cent	all	4.00	7.00

PHYSICAL REQUIREMENTS

Property	Type	Nominal Thickness, in.			
		0.004	0.006	0.007	0.010
Bursting strength, dry, individual roll average, min, psi	1	9	13	15	21
	2	8	12	14	20
	3	17	25	30	43
	4	17	25	30	43
Tensile strength, dry, machine direction, individual roll average, min, lb per in. of width	1	7	10	12	16
	2	8	11	13	18
	3	14	21	25	36
	4	14	21	25	36
Tensile strength, dry, cross machine direction, individual roll average, min, lb per in. of width	1	4	6	7	9
	2	4	5	6	8
	3	7	10	12	17
	4	7	10	12	17
Tensile strength, wet, machine direction, individual roll average, min, lb per in. of width	1	0.20	0.30	0.40	0.50
	2	0.20	0.30	0.40	0.50
	3	0.35	0.50	0.60	0.85
	4	0.55	0.75	1.00	1.40
Air resistance, sec per 100 cu cm per sq in.	1	2.0 to 3.0	3.0 to 4.0	3.5 to 5.0	5.0 to 7.0
	2	1.5 to 2.5	2.0 to 3.5	2.5 to 4.0	4.0 to 6.0
	3	1.0 to 2.5	1.8 to 3.5	2.0 to 4.0	3.0 to 6.0
	4	1.0 to 2.5	1.8 to 3.5	2.0 to 4.0	3.0 to 6.0
Impregnation time Side A, max, sec.	1	13	20	23	32
	2	13	20	23	32
	3	10	15	18	25
	4	12	18	21	30
Side B, max, sec.	1	16	24	28	40
	2	16	24	28	40
	3	17	25	30	43
	4	20	30	35	50

DIMENSIONAL REQUIREMENTS

	Type	Nominal Thickness, in.			
		0.004	0.006	0.007	0.010
Basis weight (25 by 40–500) lb	1	33.0	50.0	57.0	79.0
	2	33.0	50.0	57.0	79.0
	3	33.0	50.0	57.0	79.0
	4	34.0	51.0	60.0	86.0

TENTATIVE ADOPTED AS STANDARD

The committee recommends that the Tentative Methods of Measuring Dimensions of Rigid Rods Used in Electrical Insulation (D 741 – 47 T) be approved for reference to letter ballot of the Society for adoption as standard.

WITHDRAWAL OF STANDARD

The committee recommends the withdrawal of the Standard Methods of Testing Electrical Insulating Oils (D 117 – 43) as these methods have now been superseded by the Tentative Methods of Testing Electrical Insulating Oils (D 117 – 50 T).

REAFFIRMATION OF STANDARDS

The committee recommends the reaffirmation of the following seven standards which have been published for six years or longer without revision:

Molding Powders Used in Manufacturing Molded Electrical Insulators (D 392 – 38),

Pin-Type, Lime-Glass Insulators (D 468 – 46),

Glass Spool Insulators (D 550 – 44),

Steatite Used as Electrical Insulation (D 667 – 44),

Acetone Extraction of Phenolic Molded or Laminated Products (D 494 – 46).

Punching Quality of Phenolic Laminated Sheets (D 617 – 44), and

Product Uniformity of Phenolic Laminated Sheets (D 634 – 44).

REPORT OF COMMITTEE D-10

ON

SHIPPING CONTAINERS*

Committee D-10 held a Fall Meeting in Cleveland, Ohio, on October 5, 1951, and a Spring Meeting in Atlantic City, N. J., on April 1, 1952. The Fall Meeting included a discussion of strain gages by W. M. Bertolet of the Baldwin-Lima-Hamilton Corp., and illustrations of the use of strain gages in package testing by John G. Turk of the Preston Laboratories. The Spring Meeting featured two motion pictures of package testing, one by Earl Stivers, and the other by W. B. Keefe of the Safe Transit Program of the Porcelain Enamel Institute.

One action completed during the year on standards was the approval of the pallet test method (D 1185 - 51 T).[1] A Tentative Method of Test for Water Vapor Permeability of Shipping Containers by Cycle Method is being submitted to letter ballot of the committee.

Officers elected for the ensuing two-year term are:

Chairman, T. A. Carlson.
Vice-Chairman, Earl Stivers.
Secretary, J. H. Toulouse.
Advisory Board, A. V. Grundy and Charles Miller.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Definitions of Terms (Edward Dahill, chairman) has added several new definitions to the "Glossary of Terms."

Subcommittee II on Methods of Testing (G. E. Falkenau, chairman) has several studies under way. One group has met several times to consider revisions in the vibration test (D 999 - 48 T)[2] and has undertaken a cooperative test program. A second group is developing a puncture test method for multiwall paper shipping sacks. A third group is studying a reduction in the variables found in the revolving drum test (D 782 - 47).[2] A fourth group considered the proposed addition of tests using double slings in the test of large shipping cases and crates (D 1083 - 50 T),[3] and action was taken to advance D 1083 to standard without inclusion of the end and side sling test.

Subcommittee III on Moisture and Vapor Resistance (H. A. Bergstrom, chairman) has completed action on the cycle test for water permeability of shipping containers and submitted it to the entire committee. Additional cycle tests have been discussed.

Subcommittee IV on Performance Standards (J. G. Turk, chairman) has set up five task groups. One group on the vibration test has planned studies which pertain to both Subcommittees II and IV. The compression task group is studying the results of a previous round-robin test before setting up a program. The drop and conbur task group is studying the results of a round-robin drop test. Another group has made tentative recommendations as to the order of testing, and a fifth group has recommended standard temperature and humidity levels for tests not otherwise specified as to these conditions.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] 1951 Supplement to 1949 Book of ASTM Standards, Part 4.

[2] 1949 Book of ASTM Standards, Part 4.

[3] 1950 Supplement to 1949 Book of ASTM Standards, Part 4.

Subcommittee V on Correlation of Tests and Test Results (R. C. McKee, chairman) has also been very active in cooperative testing. Two round-robin drum tests and a drop test have been completed and the results reported by a statistical task group. Variability between laboratories using both the drop and the drum test is far greater than had been expected and will delay the setting of performance standards.

Subcommittee VI on Interior Packing (S. L. Swenson, chairman) has spent considerable time evaluating cushioning materials, with an excellent bibliography of the function and measurement of these materials by Lynn Hokenson. D. C. Wamsley submitted a plan of sequence of steps and objectives in evaluating materials for shock absorption. Dave Herrick addressed the subcommittee at the Spring Meeting on the application of cushioning materials, following which a task force was set up to study the available equipment for evaluating cushioning materials, and another for standardizing their evaluation.

The Joint ASTM–TAPPI Committee on Shipping Containers has set up its organization for unifying the test methods of both groups, with the exchange of preliminary test information, but with independent approval action in all cases.

The membership consists of 92 members, of whom 33 are producers, 38 consumers, and 21 general interest members.

This report has been submitted to letter ballot of the committee which consists of 85 voting members; 50 members returned their ballot all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

T. A. CARLSON,
Chairman.

JULIAN H. TOULOUSE,
Secretary.

REPORT OF COMMITTEE D-11

ON

RUBBER AND RUBBER-LIKE MATERIALS*

Committee D-11 on Rubber and Rubber-Like Materials, and sixteen of its subcommittees, held meetings in Cleveland, Ohio, on March 5 to 7, during ASTM Committee Week. In addition, several of the subcommittees have held separate meetings during the year.

The committee was represented at the fourth meeting of the International Standardization Organization Technical Committee 45 on Rubber, in Oxford, England, October 1 to 5, 1951, by R. D. Stiehler, National Bureau of Standards, R. S. Havenhill, St. Joseph Lead Co., and Miss Ethel Levene, U. S. Navy Department, Bureau of Ships. Dr. Stiehler, who was leader of the U. S. Delegation, has reported that the use of ASTM standard methods on a worldwide scale was very evident at the meeting. In consequence, serious consideration must be given to the international aspect of such standards, including the selection of units of measurement, which should be in the metric system wherever possible. Draft proposals were approved for submission to member countries on tension stress-strain testing, tear strength testing, hardness testing, rubber-to-fabric adhesion, and abrasion testing with the duPont abrader. Substantial progress was made on a number of other subjects.

Considerable progress has been made on the establishment of a uniform standard crude natural rubber for use in test formulations. Special lots of rubber prepared by the U. S. Rubber Co., under the direction of E. M. McColm, have been tested at the National Bureau of Standards and indicate good within-bale and between-bale uniformity. Work is continuing on the selection of the most desirable material with respect to Mooney viscosity and curing rate for use in standard samples.

A Symposium on Recent Developments in the Evaluation of Natural Rubber,[1] comprising eight technical papers has been arranged by a special symposium committee headed by Norman Bekkedahl, chairman of Subcommittee XII, and is being held at this Annual Meeting under the sponsorship of Committee D-11.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

The following recommendations presented to the Society through the Administrative Committee on Standards were accepted on May 6, 1952:

Tentative Methods of:

Test for Adhesives for Brake Lining and Other Friction Materials (D 1205 – 52 T),

Revision of Tentative Methods of:

Testing Compressed Asbestos Sheet Packing (D 733 – 52 T),

Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Crack Growth (D 813 – 52 T),

Test for Viscosity of Rubber and Rubber-Like Materials by the Shearing Disk Viscometer (D 927 – 52 T),

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Issued as separate publication *ASTM STP No. 136* (1952).

Test for Mechanical Properties of Elastomeric Vulcanizates Under Compressive or Shear Strains by the Mechanical Oscillograph (D 945 – 52 T).

Revision of Tentative Specifications and Methods of Test for:

Latex Foam Rubbers (D 1055 – 52 T),
Sponge and Expanded Cellular Rubber Products (D 1056 – 52 T), and
Concentrated, Ammonia Preserved, Creamed, and Centrifuged Natural Rubber Latex (D 1076 – 52 T).

Approval of the following recommendations of Committee D-11 was accorded by the Standards Committee on May 14, 1952:

Reinstatement of Tentative Method of:

Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (D 736 – 46 T).

Tentative Specifications for:

Rubber Insulating Gloves (D 120 – 52 T),

Tentative Method of:

Test for Resistance to Aging of Vulcanized Rubber by Measurement of Creep (D 1206 – 52 T),

Tentative Recommended Practice for:

Classifying Elastomeric Compositions for Resilient Automotive Mountings (D 1207 – 52 T),

Revision of Tentative Specifications for:

Insulated Wire and Cable: Class AO, 30 per cent Hevea Rubber Compound (D 27 – 52 T),
Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 – 52 T),
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 – 52 T),
Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 – 52 T),

Revision and Reversion to Tentative of Standard Specifications for:

Insulated Wire and Cable: Performance Rubber Compound (D 353 – 52 T),
Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 – 52 T),

Withdrawal of Standard Specifications for:

Electrical Gloves (Voltage Rating of Gloves, 3000 volts) (D 120 – 40).

The above recommendations approved by the Standards Committee on May 6 and 14, 1952, will appear in the 1952 Compilation of ASTM Standards on Rubber and Rubber-Like Materials, as well as in the 1952 Book of ASTM Standards, Part 6, bearing the designations indicated above.

The new tentative specifications for Rubber Insulating Gloves (D 120 – 52 T), and the withdrawal of the previous standard issued in 1940 are the result of several years work by Subcommittee IV, which also functions as ASA Sectional Committee J6 on Protective Equipment for Electrical Workers. This represents a complete re-working of the previous specifications, and recognizes three classes of gloves distinguished by their insulation levels, as determined by proof voltage test. The Tentative Methods of Test for Adhesives for Brake Lining and Other Friction Materials have been developed to fill a need created by widespread adoption of the use of adhesives instead of riveting for application of brake linings in automotive practice. Proper evaluation of the adhesives and the techniques of application is essential. The New Tentative Method of Test for Resistance to Aging of Vulcanized Rubber by Measurement of Creep was developed in connection with work of trying to improve means of evaluating aging characteristics of rubber compounds. Investigation by the committee and the National Bureau of Standards indicates that the method has considerable merit, and publication in standard form will provide greater availability and more extensive trial. The Tentative Recommended Practice for Classifying Elastomeric Compositions for Resilient Automotive Mountings is the result of work in the SAE-ASTM Technical Committee on Automotive Rubber to aid automotive engineers in selecting compositions having the desired characteristics for the particular applications intended. It supplements Tentative Specifications D 735 on Automotive Rubber Compounds as applied to this specialized field.

The revision of the Tentative Methods of Testing Compressed Asbestos Sheet Packing (D 733) changes the methods of measuring thickness, and of determining tensile strength to conform with latest practice, and incorporates, by reference, Method D 1147 for Compressability and Recovery. In the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735), a new table has been added to cover the increasing use of Silicone compounds for high- and low-temperature resistance. The tests required by certain of the suffix letters have also been clarified, and some additional grades of rubber compounds which are needed have been added. The revision of the Tentative Method of Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Crack Growth (D 813) makes numerous changes intended to bring the method up to date and to make it more usable. A new and better piercing tool of the spear type is specified for initiating the crack, as this has been found to improve reproducibility of results. In the Test for Mooney Viscosity (D 927) details in the operation of the test machine which have been found desirable have been changed, and a note on temperature gradient and heat transfer has been added. In the test for Mechanical Properties of Rubber, Using the Yerzley Oscillograph (D 945) the constant in the formula for K_s in Section 9 has been changed from 185 to 105. The previous value has been found to be incorrect.

In the revision of the Specifications and Tests for Latex Foam Rubbers (D 1055) the procedure for the compression set test has been changed to eliminate unnecessary provisions, and similar changes have been made in the Specifications and Tests for Sponge and Expanded Cellular Rubbers (D 1056). In the latter case additional changes provide for the use of the weather-resistance and exposure test (D 1171) with sponge rubbers and alter the length and width tolerances on sheet and strip sponge as given in the appendix of the specifications. The revisions in the Specifications and Tests for Natural Rubber Latex (D 1076) have resulted from discussions in ISO Technical Committee 45. They permit use of metal weighing dishes in the total solids determination and change the procedure for determining total alkalinity. A method for determining pH has also been added, and the amount of KOH used in the determination of KOH number has been reduced.

In the revisions of Insulated Wire Specifications, Class AO (D 27), Heat-Resisting Synthetic Rubber Compound (D 754), and Performance Synthetic Rubber Compound (D 755), and in the revision and reversion to tentative of the Standard Specifications for Performance Rubber Compound (D 353) and Heat-Resisting Rubber Compound (D 469), changes have been made in each case in Table I on physical test requirements for insulation to bring these requirements in line with current practice. In addition, provisions have been added covering stranded conductors insulated for over 1000 v.

The reinstatement of the Test for Low-Temperature Brittleness (D 736) was requested by the SAE-ASTM Technical Committee on Automotive Rubber, which stated that the method is needed for use with Silicone rubbers, and is still in use for evaluation of brittleness characteristics as distinct from measurement of brittle temperature. In reinstating this method a note has been added recommending the use of the Method for Brittle Temperature (D 746) in new specifications and calling attention to the fact that D 736 is inherently less accurate because of its lack of control of rate of force application. Although the committee has recognized the present need for continuing the publication of Method D 736, it is expected that this will eventually be replaced by the more accurate equipment and procedure specified in Method D 746.

NEW TENTATIVES

Committee D-11 recommends the acceptance for publication of the New Tentative Method of Test for Low-Temperature Compression Set of Vulcanized Elastomers, appended hereto.[2] This tentative is badly needed to provide in standard form a test procedure which is being used extensively for the evaluation of rubber products intended for service in low-temperature environments.

REVISION OF TENTATIVES

The committee recommends that seven of the present tentatives be revised as indicated, and continued as tentative:

Tentative Methods of Sample Preparation for Physical Testing of Rubber Products (**D 15 – 50 T**).[3] This revision consists of a complete re-writing of the methods for sample preparation, as appended hereto.[4] Subcommittee X has been working for several years on bringing the former methods up to date to include the various changes which have been occasioned by the use of synthetic rubbers, and to rearrange the methods so as to increase their usability. The proposed methods give standard formulations for test purposes which use the standard ingredients developed by the special subcommittee on standard samples in cooperation with the National Bureau of Standards. Mixing procedures for the different types of synthetic rubbers are also given. In this work it has been found desirable to divide the sample preparation methods into three classes, the first of which includes the procedures for compounding and mixing of standard compounds utilizing standard ingredients. The second part applies to the preparation of samples for tension testing from mixed batches of rubber compounds. This includes the vulcanization procedure and is applicable to either laboratory- or factory-mixed stock. The third part deals with the preparation of a test specimen from a rubber sample which is not necessarily a test slab, and includes procedures for separating rubber from fabrics in finished products and buffing as required.

Tentative Specifications for Friction Tape for General Use for Electrical Purposes (**D 69 – 48 T**).[3] In this revision it is recommended that Section 8 be revised by replacing the values for maximum permissible number of pinholes, now given, by those values specified in the Emergency Alternate Provisions EA–D69 which are being withdrawn. Experience with emergency alternate tape has shown that the proposed relaxation of the previous requirement is justified. The revision is as follows:

Section 8.—Change the requirements for the number of pinholes in a specimen of three consecutive yards of tape to read as follows:

Tape Width, in.	Number of Pinholes, max
$\frac{3}{4}$	12
1	16
$1\frac{1}{2}$	24
2	32

Tentative Methods of Test for Compression Set of Vulcanized Rubber (**D 395 – 49 T**).[3]—The following changes in these methods are recommended. It is believed that control of the loading by specifying the thickness of spacer bars used is more positive than the previous method.

Section 6: Special Test Specimens.—Add the following sentence: "For Method B compression set, the specimen shall be deflected in accordance with the percentage values shown in the table in Section 11 (*b*)."

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[2] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 6.

[3] 1949 Book of ASTM Standards, Part 6.

[4] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 6.

Section 11 (*b*): *Application of Load.*—Change the table of durometer hardness number and per cent deflection to the following:

Durometer Hardness Number	Thickness of Spacer Bar, in.	Deflection, percentage of original thickness
Up to 44, incl.	0.300 ± 0.001	40
45 to 64, incl.	0.350 ± 0.001	30
65 to 84, incl.	0.375 ± 0.001	25
85 and over	0.400 ± 0.001	20

Tentative Methods of Testing Rubber Insulated Wire and Cable (**D 470– 50 T**).[5] The following changes in these methods are recommended:

Section 4: Test Specimens.—Change the first sentence of the present Paragraph (*d*) on Condition and Age by deleting the reference to covering, so that it reads: "Samples of the insulated wire and cable for physical and accelerated aging tests shall be taken after vulcanization."

Insert the following as a new Paragraph (*d*) and re-letter the present Paragraphs (*d*) and (*e*):

> (*d*) In the case of wires or cables having a thin jacket vulcanized directly to the insulation, it is usually necessary to prepare die-cut specimens of the jacket and insulation. An effort should be made to separate the jacket from the insulation by slitting the covering through the conductor, and pulling the jacket and insulation apart by means of pliers. This procedure may sometimes be facilitated by immersing the sample in hot water for a few minutes just prior to pulling off the jacket. If the jacket cannot be pulled off it will be necessary to prepare specimens by buffing. The buffing apparatus for this operation should be equipped with a cylindrical table arranged so that it can be advanced very gradually. Two short lengths of wire are taken, and the conductor removed by slitting the covering. One length of covering is stretched into the clamps of the buffing apparatus so that it lies out flat, with the jacket toward the wheel. The jacket is buffed off with due care not to buff any further than necessary. The process is repeated with the other length of covering, except that the insulation is buffed off. Die-cut specimens may be prepared from the buffed pieces after they have been allowed to recover for at least 30 minutes. In the case of specimens from small wires, it may be necessary to use a die having a constricted portion $\frac{1}{8}$ in. wide instead of $\frac{1}{4}$ in. wide. Jackets with a thickness of less than $\frac{1}{32}$ in. shall not be tested.

This revision has been under consideration for some time. It had first been submitted to the Administrative Committee on Standards, but in view of certain negative viewpoints expressed, the Standards Committee asked that those viewpoints be examined. This has been done, and the subcommittee in charge asks that the proposed revisions be submitted without change.

Section 15: Voltage Test Procedure.—Delete the second sentence referring to d-c voltage.

Sections 15 (*b*) *and* (*c*).—Change the immersion period from "12 hr" to "6 hr."

Section 17: Procedure.—Change the last sentence to specify a–c voltage as follows: ". . . shall be subjected for 5 min to an a–c voltage equal to twice that specified in Section 15."

Section 25.—Insert the following procedure for determining temperature correction factors for insulation resistance as a new Section 25, and renumber succeeding sections:

> 25. (*a*) Three samples, preferably of No. 14 AWG solid wire with a $\frac{2}{64}$-in. wall of insulation, shall be selected as representative of the insulation under consideration. They should be of sufficient length to yield insulation resistance values under 25,000 megohms at the lowest water bath temperature.
>
> (*b*) The three samples shall be immersed in a water bath equipped with heating, cooling, and circulating facilities with the ends of the samples extended 2 ft above the surface of the water and properly prepared for minimum leakage. The samples shall be left in the water at room temperature for 16 hr before the bath temperature is adjusted to 10 C, or the samples transferred to a 10 C test temperature bath.
>
> (*c*) The resistance of the conductor shall be

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[5] 1950 Supplement to Book of ASTM Standards, Part 6.

measured at suitable intervals of time until it is unchanged for at least 5 min. The insulation will then be at the temperature of the bath as read on the bath thermometer. Insulation resistance readings shall be measured in accordance with Sections 21, 22, and 23.

(*d*) The three samples shall be exposed to successive water bath temperatures of 10 C, 16 C, 22 C, 28 C, and 35 C, returning to 28 C, 22 C, 16 C, and 10 C. Insulation resistance readings shall be taken at each temperature after equilibrium is established.

(*e*) The readings taken at the same temperature shall be averaged and plotted on semi-log paper. The insulation resistance value at 15.6 C (60 F) shall be read from the plot.

(*f*) Correction factors for any temperature shall be obtained by dividing the value of insulation resistance at this temperature, by the insulation resistance at 15.6 C (60 F) as derived from the curve. The resulting correction factors are applicable only to the particular compound under test.

Tentative Methods of Test for Changes in Properties of Rubber, and Rubber-Like Materials in Liquids (**D 471 – 51 T**).[6] This revision changes the standard reference fuels recommended for immersion tests from diisobutylene with and without addition of aromatics to *iso*octane and a mixture of *iso*octane and toluene. These new fuels conform with standard test fluids being currently required by military specifications, and since their action may in some cases be slightly different from the previous reference fuels, Nos. 1 and 2, their identification is being changed by use of the letters A and B. A number of other details in the test methods are also being altered to increase their utility and to bring them in line with current practice. The detailed changes are as follows:

Section 1: Scope.—Delete the last sentence and change the next to the last sentence to read: "They are designed for testing any vulcanized rubber or rubber-like composition in the form of standard laboratory test sheets or samples cut from a finished article of commerce."

Section 2 (a): Types of Test.—Change the last sentence to read as follows by the addition of the italicized words: "The physical properties used are changes in weight, volume, tensile strength, ultimate elongation and *durometer hardness*, as well as visual and manual inspection."

Section 3: Test Conditions.—Change Paragraph (*a*) to read as follows:

3. (*a*) *Temperature.*—A suitable test temperature shall be chosen depending upon the conditions of the expected service. It shall be equal to or higher than the anticipated service temperature. In comparative tests, identical temperatures shall be employed. Use of one of the following temperatures is recommended: 73.4 ± 2 F (23 ± 1.1 C); 158 ± 1.8 F (70 ± 1 C); or 212 ± 1.8 F (100 ± 1 C). When the testing room temperature is other than 73.4 ± 2 F (23 ± 1.1 C), the report shall include a statement of the actual temperature at the time of test.

In Paragraph (*b*) change the suggested immersion periods to: "22 ± $\frac{1}{4}$ hr, 70 ± $\frac{1}{4}$ hr, 166 ± $\frac{1}{2}$ hr, and 30 days." Reason for this change is that several laboratories desire two hours less than multiples of 24 hr in order to allow technicians sufficient time to test specimens from one series of immersions before the start of the next series of immersions.

Section 4 (b): Standard Test Liquids.—In Table II replace Reference Fuels Nos. 1 and 2 throughout this section as follows:

Reference Fuel A......	*Iso*octane[a]
Reference Fuel B......	*Iso*octane,[a] 7 volumes Toluene,[b] 3 volumes

[a] *Iso*octane conforming to ASTM *Iso*octane, p. 111, Section 217 of the ASTM Manual of Engine Test Methods for Rating Fuels (1948) and p. 12 of the January, 1950, Appendix of this Manual.

[b] Toluene conforming to the Standard Specification for Industrial Grade Toluene (ASTM Designation: D 842), 1950 Supplement to Book of ASTM Standards, Part 5.

Section 6 (a): Apparatus.—Delete the word "cork" throughout this section and add the following as a note: "NOTE.—The stopper shall not contaminate the test liquid—when in doubt cover the stopper with aluminum foil." In the third sentence after "250 F" add "(121 C)."

Section 7: Test Specimens.—Change Paragraph (*a*) to read as follows:

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[6] 1951 Supplement to Book of ASTM Standards, Part 6.

7. (*a*) The test specimens shall be cut longitudinally from vulcanized sheets and, unless otherwise specified, specimens from commercial articles shall be cut in any direction.

Change Paragraph (*b*) to read as follows:

(*b*) For the determination of changes in weight or volume and for visual or manual inspection, specimens from vulcanized sheets shall be rectangular having dimensions of 1 by 2 by 0.075 in. ± 0.005 in. Specimens from commercial articles shall be the thickness of the material as received when it is less than 0.075 in., otherwise they shall be buffed to a thickness of 0.075 ± 0.005 in. Even though specimens of different thicknesses may be tested, data obtained on specimens having different original thicknesses shall not be compared.

In Paragraph (*c*) in the fourth line after the word "specimens" insert "be cut from vulcanized sheets." Add the following sentence at the end of the paragraph: "Specimens from commercial articles shall be prepared as described in ASTM Method D 412."

In Paragraph (*d*) insert the following: "For the determination of change in durometer hardness, the specimens shall conform to the requirements of indentation of rubber by means of a durometer (ASTM Designation: D 676)." Reletter Paragraph (*d*) as (*e*) and change to read as follows:

(*e*) For the determination of changes in weight and volume, at least three specimens shall be used for each determination and the results averaged. The determination of durometer hardness shall be as described in ASTM Method D 676 and the results averaged. For the determination of tensile strength and elongation, the number of specimens used shall be as described in ASTM Method D 412 and the median value used.

Section 8: Increase in Weight.—Insert in third sentence after the word air oven: "or liquid bath."

Section 9 (a): Increase in Volume.—After the first sentence insert: "A Jolly spring balance adequately shielded from air currents may be used for making these determinations."

Section 10 (c): Change in Tensile Strength, Elongation, and Durometer Hardness.—Insert in the second sentence after the word air oven: "or liquid bath."

Section 12: Apparatus.—In Paragraph (*a*) change the third sentence to read 'Small stoppers (see Note under Section 6 (*a*)) shall be provided for use in closing the tubes and during the test when the vapor pressure of the liquid is not high." In the last sentence of this paragraph, replace the word "corks" with "stoppers."

In Paragraph (*b*) change the word "cork" to "stopper."

Section 14 (a): Procedure.—Replace the word "corked" with "stoppered."

Tentative Method of Heat Aging of Vulcanized Natural or Synthetic Rubber by Test Tube Method (**D 865 - 50 T**).[3] The following changes in this method are recommended:

Section 5 (a): Test Specimens.—Add the following sentence: "At least 24 hr must elapse between completion of the vulcanization of the specimens and the start of the aging test."

Section 6: Number of Test Specimens.—Change this section to read as follows:

6. *Number of Test Specimens.*—(*a*) At least three test specimens shall be used to determine the original physical properties of each sample and also three or more specimens of the same material for each exposure period of the test.

(*b*) When minimum requirements are specified, one test shall be made for tensile strength and elongation. If the results are below the specified requirements, two additional specimens shall be prepared from the original sample and tested. Should the results of either of these tests be below the specified requirements, the samples shall be considered to have failed to meet the specifications.

Section 7: Tests of Unaged Specimens.—Change this section to read as follows:

7. *Tests of Unaged Specimens.*—(*a*) The stress-strain properties or tensile strength and ultimate elongation and any other required properties of the original unaged specimens shall be determined within 96 hr of the start of the aging period. Results on specimens which are found to be imperfect shall be discarded and retests shall be made.

(*b*) When rubber compounds are to be tested for the purpose of determining compliance with a specification, it shall be permissible to determine the original properties required in Paragraph (*a*) simultaneously with the determination of the values after the first aging period even though the elapsed time exceeds 96 hr.

Section 9: Physical Tests of the Aged Specimens.—Retain the first sentence as now written and rewrite the remainder as follows:

> In determining the physical properties after aging, the final values shall be the median of results from three specimens except that under the following conditions two additional specimens shall be exposed and tested and the median of the values for the five specimens shall be used:
>
> (*1*) If one or more values do not meet the specified requirements when testing for compliance with specifications.
>
> (*2*) If referee tests are being made. After completion of the tests, the broken specimens shall be examined visually and manually and their condition noted.

These revisions will improve the uniformity of the present aging test procedures and will bring them into conformity with the present tension test Method D 412.

Tentative Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-like Materials by the Gehman Torsional Apparatus (**D 1053 – 51 T**).[5] Add to Section 2 (*c*) Torsion Apparatus, in the form of a Note, the following method for calibration of torsion wire and determination of the torsional constant:

> NOTE.—Insert one end of the torsion wire in a vertical position, in a fixed clamp, and set the lower end of the wire at the exact center of a rod of known dimension and weight. (For standardization purposes, it is suggested that the rod be 8 to 10 in. long and about ¼ in. in diameter.) The rod should be allowed to oscillate freely and the time required for 20 oscillations noted in seconds.
>
> To calculate the mass moment of inertia, use the equation:
>
> $$I = \frac{l}{12} m l^2$$
>
> where:
>
> I = moment of inertia, in gram centimeters squared,
>
> m = mass in grams, and
>
> l = length in centimeters.
>
> Use the following equation to calculate the torsional constant:
>
> $$\lambda = \frac{4\pi^2 I}{T^2}$$
>
> where:
>
> T = period of one oscillation, in seconds,
>
> I = moment of inertia of the rod, in gram centimeters squared, and
>
> λ = restoring force exerted by the wire, in dyne-centimeters per radian of twist.
>
> To change from dyne-centimeter per radian of twist to gram-centimeter per degree, use the following formula:
>
> $$\text{Torsional constant, } K = \frac{\lambda \times \pi}{981 \times 180}$$

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Standard Method of Air Pressure Heat Test of Vulcanized Rubber (**D 454 – 50**),

Standard Method of Test for Accelerated Aging of Vulcanized Rubber by the Oxygen-Pressure Method (**D 572 – 50**), and

Standard Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (**D 573 – 48**).

The committee recommends for immediate adoption the same revisions in the corresponding paragraphs of these three standard methods as recommended above in the Tentative Method of Heat Aging by the Test Tube Method (D 865). The reasons are the same in all cases and it is considered desirable to have the changes published simultaneously. The committee accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

REVERSION OF STANDARD TO TENTATIVE

Standard Method of Test for Hardness of Rubber (**D 314 – 39**): This action is requested to expedite revision, which will include recommendations on calibration and care of the instruments and details of operation which must be observed to insure reproducible readings.

WITHDRAWAL OF TENTATIVE

The committee recommends the withdrawal of the Tentative Specifications for Natural Rubber Cups for use in Hydraulic Actuating Cylinders (D 818 – 45 T).

The SAE-ASTM Technical Committee on Automotive Rubber, which prepared these specifications, have recommended that they be published only by SAE, since they are used almost exclusively in the automotive industry.

WITHDRAWAL OF EMERGENCY ALTERNATE PROVISIONS

The committee recommends the withdrawal of the present emergency alternate provisions in the Tentative Specifications for Friction Tape (D 69 – 48 T), and the Tentative Specifications for Rubber Insulating Tape (D 119 – 48 T). With more adequate supplies of crude natural rubber available, the need for these provisions no longer exists.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that all tentatives under its jurisdiction, other than those mentioned in this report, be continued as tentative. Most of these are being reviewed by the various subcommittees, and the results of this work will be presented to the Society as it is completed.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[7]

ACTIVITIES OF SUBCOMMITTEES

Appointment of Mr. F. M. Galloway as chairman of Subcommittee II on Belting has been announced. Also Mr. L. Cranston has resigned as chairman of Subcommittee I on Mechanical Rubber Hose, but his successor has not yet been appointed.

Nearly all of the various subcommittees of Committee D-11 have been very active during the year. Subcommittee V on Insulated Wire and Cable is undertaking the reorganization and enlargement of all of its specifications for wire and cable. It expects to develop a new master specification covering constructional details of wires and cables for power usage. All testing and sampling procedures will be consolidated in a single enlarged version of Methods D 470. The other specifications will be concerned only with the physical and electrical properties of the individual types of compound. When these revisions are completed it is expected that a complete product may be purchased by means of ASTM specifications, and that this arrangement will fill a real need commercially.

The study of relaxation characteristics of rubber is receiving attention in several subcommittees, including Subcommittee VI on Packings, Subcommittee XVII on Tests of Hardness, Set and Creep, and in the SAE – ASTM Technical Committee on Automotive Rubber. Subcommittee IX on Insulating Tape expects to have a new tentative specification for ozone-resistant tape ready for presentation to the Society. It is also studying the sampling procedures used for tape.

A large amount of investigative work is in progress in other subcommittees, and will eventually result in new methods of test and numerous revisions of existing methods.

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[7] The letter ballot vote on these recommendations was favorable; the results of this vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 211 members; 124 members returned their ballots, of whom 114 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. COLLIER,
Chairman.

ARTHUR W. CARPENTER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Methods of:

Testing Automotive Hydraulic Brake Hose (D 571 - 51 T),
Test for Compression Fatigue of Vulcanized Rubber (D 623 - 41 T),
Testing Asphalt Composition Battery Containers (D 639 - 51 T),
Testing Compression Asbestos Sheet Packing (D 733 - 50 T),
Testing Rubber-Coated Fabrics (D 751 - 46 T),
Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Cut Growth by the Use of the Ross Flexing Machine (D 1052 - 49 T), and
Measuring Low-Temperature Stiffening or Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus (D 1053 - 52 T).

Revision of Tentative Specifications for:

Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 - 52 T).

Revision of Tentative Specifications and Methods of Test for:

Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076 - 52 T).

Withdrawal of Standard Methods of:

Sampling and Testing Latices of Natural Rubber and Synthetic Rubbers (D 640 - 44).

These recommendations were accepted by the Standards Committee on November 13, 1952, and the revised methods and specifications appear in the 1952 Book of ASTM Standards, Part 6.

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS*

Committee D-12 on Soaps and Other Detergents held one meeting during the year on March 17 and 18, 1952, in New York City. At this meeting the following officers were elected for the ensuing term of two years:

Chairman, J. C. Harris.
Vice-Chairman, Frederick Krassner.
Secretary, H. R. Suter.

During the year Mr. J. A. Woodhead resigned the chairmanship of Subcommittee T-5 and Anthony M. Schwartz was appointed to this office. Mr. Rubin Bernstein was appointed as chairman of Subcommittee T-2 on Analysis of Synthetic Detergents, which has now resumed activities.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

Committee D-12 recommends that the following proposed methods of test be published as information, as appended hereto:[1]

Proposed Methods of Test for Surface and Interfacial Tension of Solutions of Surface-Active Agents,
Proposed Method of Test for Rinsing Properties of Metal Cleaners,
Proposed Method of Test for Buffering Action of Metal Cleaners, and
Proposed Method of Total Immersion Corrosion Test for Soak Tank Metal Cleaners.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the following tentative be approved and referred to letter ballot of the Society for adoption as standard:

Tentative Specifications for
Sodium Bicarbonate (**D 928 - 47 T**).[2]

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions in four standards and requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Palm Oil Solid Soap (**D 535 - 41**).[2]—Revise to provide for an increase in the permissible value for "Sum of free alkali or free acid, total matter insoluble in alcohol, and sodium chloride, max., per cent" from 3.0 to 4.0.

Standard Specifications for Palm Oil Chip Soap (**D 536 - 42**).[2]—Revise to provide for an increase in the permissible value for "Sum of free alkali or free acid, total matter insoluble in alcohol, and sodium chloride, max, per cent" from 4.0 to 6.0.

Standard Specifications for Ordinary Bar Soap (**D 497 - 39**).[2]—Change the title to read "Standard Specifications for Ordinary Laundry Bar Soap." Also, revise to provide for a change in the permissible values for "Sum of free alkali or free acid, total matter insoluble in alcohol, and sodium chloride, per cent" from "2.0 to 10" to "2.0 to 11."

Standard Definitions of Terms Relating to Soaps and Other Detergents (**D 459 -**

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] See pp. 447 to 455.

[2] 1949 Book of ASTM Standards, Part 5.

51).[3]—The committee recommends the inclusion of the following additional definitions:

Neutral Soap.—An essentially unbuilt soap substantially free from uncombined alkali or fatty matter.

Active Ingredient of a Synthetic Detergent.—The organic surface-active material present in the detergent.

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following standards be continued without revision:

Standard Methods of:

Sampling and Chemical Analysis of Soaps and Soap Products (**D 460 – 46**),[2]
Chemical Analysis of Soaps Containing Synthetic Detergents (**D 820 – 46**),[2]
Chemical Analysis of Sulfonated and Sulfated Oils (**D 500 – 45**),[2]
Chemical Analysis of Industrial Metal Cleaning Compositions (**D 800 – 45**),[2] and
Test for Particle Size of Soaps and Other Detergents (**D 502 – 39**).[2]

Standard Specifications for:

Built Soap, Powdered (**D 533 – 44**),[2]
Alkaline Soap Powder (**D 534 – 42**),[2]
Soda Ash (**D 458 – 39**),[2]
Modified Soda (Sesquicarbonate Type) (**D 457 – 39**),[2]
Sodium Metasilicate (**D 537 – 41**),[2]
Sodium Sesquisilicate (**D 594 – 41**),[2] and
Trisodium Phosphate (**D 538 – 44**).[2]

EDITORIAL CHANGES

The committee recommends that the following three standards be editorially revised as indicated:

Standard Specifications for Caustic Soda (**D 456 – 39**).[2]—In the title and in Sections 2, 3, and 4, following the words "caustic soda" insert the word "(anhydrous)."

Standard Specifications for Tetrasodium Pyrophosphate (Anhydrous) (**D 595 – 45**).[2]—In Section 2, insert the word "flake" so that the description reads "a white, uniform product in either granular, powdered, or flake form, as specified by the purchaser." In Section 3, change the specifications for "matter insoluble in water, max, per cent" so that it reads 0.2 instead of 0.20.

Standard Specifications for Liquid Toilet Soap (**D 799 – 51**).[3]—In Section 2, delete the phrase "(or potash and soda)" so that the sentence reads "Liquid toilet soap shall be a clear solution of pure vegetable oil, potash soap, with or without glycerol or alcohol, free from objectionable odor, and shall form a satisfactory lather."

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee T-1 on Soap Analysis (E. W. Blank, chairman).—This subcommittee, which functions jointly with a committee of the American Oil Chemists' Society, is continuing cooperative tests on a colorimetric method for the determination of copper in soap. In addition, it is investigating improved methods for the determination of carbonate and borax. The future program will include investigation of methods for the determination of sodium carboxymethyl cellulose in soap and synthetic detergents, and methods for measurement of the color of soap.

Subcommittee T-2 on Analysis of Synthetic Detergents (R. Bernstein, chairman) was reactivated in October of 1951 and is compiling a bibliography on analytical methods for synthetic detergents. Methods for identification of synthetic detergents, including infrared spectrometry, are being investigated.

Subcommittee T-4 on Analysis of Alkaline Detergents (W. H. Koch, chairman) has concluded its investigation of a referee method for the analysis of sodium bicarbonate. Methods of analysis for sodium orthosilicate are to be investigated.

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[3] 1951 Supplement to Book of ASTM Standards, Part 5.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee T-5 on Physical Testing (J. A. Woodhead, chairman).—A task committee was appointed to revise the method for the determination of pH of soaps and other detergents. The subcommittee has prepared a proposed method for surface and interfacial tension, which is appended for information only.[5]

Subcommittee T-6 on Metal Cleaning (J. C. Harris, chairman) has prepared proposed methods for the evaluation of rinsing and buffering properties of metal cleaners, and a total immersion corrosion test for soak tank cleaners, which are appended for information only.[6] Further studies are planned of methods for the evaluation of emulsification properties of metal cleaners. The subcommittee is also preparing a guide to laboratory evaluation of metal cleaners and a classification of soils occurring on metals.

Subcommittee S-1 on Specifications for Soap (Frederick Krassner, chairman) recommended revision and continuation of standards as indicated earlier in the report. Specifications for concentrated liquid soaps and grit soaps are being considered.

Subcommittee G-1 on Advisory (J. C. Harris, chairman) recommended that preparation of specifications covering liquid caustic soda not be undertaken because of lack of consumer interest. Several requests for specifications for synthetic detergents were considered and it was recommended that preparation of such specifications be deferred pending development of satisfactory analytical and performance testing methods.

Subcommittee G-5 on Program Planning (R. B. Mitchell, chairman) prepared the program presented at the meeting of Committee D-12 on March 17 and 18 in New York, N. Y., which included, in addition to the regular committee activities, presentation of the following technical papers which have been published in issues of ASTM BULLETIN:

Infrared Spectrograms on Synthetic Detergent Materials by Philip Sadtler,
Methods of Testing Detergents by E. H. Leonard, and
Metal Cleaning Before Electroplating by H. B. Lindford.

In addition, the following papers were presented at the same meeting as a Symposium on Statistical Methods for the Detergent Laboratory.[7]

*Graphical Methods of Statistical Analysis and Tests for Significance by Paul L. Schmidt, Westinghouse Electric Corp., Pittsburgh,
Comparison of Variability by L. Beck, Alexander Smith, Inc.,
Statistical Treatment of Detergency Data by J. Sherman and R. Bernstein, Philadelphia Naval Shipyard,
*The Design of Laboratory Control of Commercial Laundries Based on an Analysis of Variance by G. S. Freeman and M. I. Cohn, American Conditioning House, Inc., Boston,
*The Importance of Correlations in Detergency Testing by J. M. Lambert and E. J. Leshan, General Aniline and Film Corp., Central Research Laboratory, Easton, Pa., and
Summarization of Papers presented by O. P. Beckwith, Alexander Smith, Inc., representing Committee E-11 on Quality Control of Materials.

This report has been submitted to letter ballot of the committee, which consists of 152 members; 68 members have returned their ballots, of whom 68 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. C. HARRIS,
Chairman.

H. R. SUTER,
Secretary.

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[5] See p. 447.
[6] See pp. 452 and 455.
[7] The three papers set off by asterisks were issued as separate publication *ASTM STP No. 139.*

APPENDIX I

PROPOSED METHODS OF TEST FOR SURFACE AND INTERFACIAL TENSION OF SOLUTIONS OF SURFACE-ACTIVE AGENTS[1, 2]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. These methods cover procedures for determining surface tension and interfacial tension of solutions of surface-active agents, as defined in the Standard Definitions of Terms Relating to Soaps and Other Detergents (ASTM Designation: D 459).[3] Two methods are covered, as follows:

Method A. Surface Tension.
Method B. Interfacial Tension.

Method A is written primarily to cover aqueous solutions of surface-active agents, but is also applicable to nonaqueous solutions and mixed solvent solutions. Method B is applicable to two-phase solutions. More than one solute component may be present, including solute components that are not in themselves surface-active.

Apparatus

2. (*a*) *Tensiometer.*—Either the du Nouy precision tensiometer or the du Nouy interfacial tensiometer, equipped with either the 4- or the 6-cm circumference platinum ring, as furnished by the manufacturer, may be used. The tensiometer shall be placed on a sturdy support that is free from vibrations and other disturbances such as wind, sunlight, and heat. The wire of the ring shall in one plane, free of bends or irregularities, and circular. When set in the instrument, the plane of the ring shall be horizontal, that is, parallel to the surface plane of the liquid being tested.

(*b*) *Sample Container.*—The vessel for holding the liquid shall be not less than 6 cm in diameter, and sufficiently large to ensure that the contact angle between the ring and the interface is zero.

Preparation of Apparatus

3. (*a*) Clean all glassware thoroughly. The use of fresh chromic-sulfuric acid cleaning mixture, followed by a thorough rinsing in distilled water, is recommended.

(*b*) Clean the platinum ring by rinsing thoroughly in a suitable solvent and in distilled water, before a set of measurements is taken. Allow the ring to dry, and then heat to white heat in the oxidizing portion of a gas flame.

Calibration of Apparatus

4. The tensiometer is, in fact, a torsion balance, and the absolute accuracy depends on the length of the torsion arm, which is adjustable. Torsion may be applied to the wire by means of either the dial-adjusting screw (which controls the dial reading) or a rear adjusting screw. Calibration consists essentially in adjusting the length of the torsion arm so that the dial scale will read directly

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-12 on Soaps and Other Detergents.

[2] Published as information, June, 1952.

[3] 1951 Supplement to 1949 Book of ASTM Standards, Part 5.

in dynes per centimeter. The precision tensiometer shall be calibrated in accordance with the following Paragraphs (*a*) to (*c*); the interfacial tensiometer shall be calibrated in accordance with Paragraphs (*a*) to (*d*).

(*a*) Level the tensiometer. A liquid level of the type employed on analytical balances may be used. Place the level on the table that holds the sample for testing, and adjust the leg screws of the tensiometer until the table is horizontal. Pull the torsion wire taut by means of the tension screw, and adjust the dial reading and the vernier to zero. Insert the platinum ring in the holder, and place a small piece of paper across the ring. This will serve as a platform to hold the calibrating weight. Turn the rear adjusting screw of the torsion wire until the index level of the arm is opposite the reference line of the mirror; this automatically compensates for the weight of the paper platform. Next, place an accurately standardized weight of between 500 and 800 mg on the paper platform and turn the dial-adjusting screw until the index level of the arm is opposite the reference line of the mirror; this automatically compensates for the weight of the paper platform. Place an accurately standardized weight of between 500 and 800 mg on the paper platform, and turn the dial-adjusting screw until the index level of the arm is opposite the reference line of the mirror. Record the dial reading to 0.10 division. Call this "gamma-c."

(*b*) Calculate what the reading "gamma-c" obtained in Paragraph (*a*) *should be* when the tensiometer is properly adjusted, as follows (Note 1):

$$\gamma_c = \frac{M \times g}{2L}$$

where:

M = weight placed on the paper platform, in grams,

g = gravity constant (Note 2), in cgs units, and

L = mean circumference of the ring (furnished by the manufacturer with each ring).

If the recorded dial reading "gamma-c" is greater than the calculated value, the torsion arm should be shortened. If "gamma-c" is less than the calculated value, the torsion arm should be lengthened. Repeat the calibration procedure, readjusting the zero position after each change in the length of the torsion arm, until the dial reading agrees with the calculated value. Each unit of the scale now represents a pull on the ring of 1 dyne per cm. Note that a conversion factor, F (see Paragraph (*c*)), must be multiplied by the scale reading to give corrected surface tension in dynes per centimeter.

NOTE 1: *Example.*—If M is exactly 0.600 g, and L is 4.00 cm:

$$\gamma_c = \frac{0.600 \times 980.3}{2 \times 4.00} = 73.52 \text{ dynes per cm}$$

NOTE 2.—The gravity constant is 980.3 at Chicago; in other localities it will differ very slightly from this value.

(*c*) After the tensiometer has been calibrated, it is convenient to calculate the number of grams total pull on the ring that is represented by each scale division. This is done simply by dividing the scale reading into the weight used for calibration (Note 3). This value is used in the calculation of the conversion factor, F, mentioned in Paragraph (*b*).

NOTE 3.—In the example given in Note 1, each scale unit after calibration represents:

$$\frac{0.600}{73\ 52} = 0.008161 \text{ g}$$

(*d*) *Interfacial Tensiometer.*—With the interfacial tensiometer, the same principle of calibrating by adjusting the length of the torsion arm also applies.

This instrument has, however, in addition to the torsion arm, a torsion-arm counterbalance. Adjust the length of this counterbalance to coincide with that of the torsion arm itself, in order that the vertical members of the assembly may remain in line.

METHOD A. SURFACE TENSION

Procedure

5. (*a*) After the tensiometer has been calibrated, check the level and insert the cleaned platinum ring (Note 1) that will be used in the measurement. Check the plane of the ring, and set the dial and vernier at zero. Adjust the rear adjusting screw so that the index level of the arm is opposite the reference mark on the mirror, that is, the ring system is at the zero position.

NOTE 1.—Extreme care must be taken to have the sample vessel and platinum ring clean. Contamination of the liquid surface by dust or other atmospheric impurities during measurement should be avoided.

(*b*) Place the solution to be tested (Note 2), contained in the thoroughly cleaned vessel (Note 1), on the sample platform. Raise the sample platform by means of its adjusting screw until the ring is just submerged.

NOTE 2.—Since the surface tension of a solution is a function of the concentration, care must be taken that the concentration is adjusted and recorded within known limits. The presence of solutes other than the surface-active agent should be ascertained and reported qualitatively and quantitatively, insofar as possible. This includes hardness components in the water. Care should be taken that the solution is physically homogeneous. Measurements made near or above the cloud point or other critical solubility points can be in serious error. This is particularly true when the solute is a surface-active material.

(*c*) Lower the platform slowly, at the same time applying torsion to the wire by means of the dial-adjusting screw. These simultaneous adjustments must be carefully proportioned so that the ring system remains constantly in its zero position. As the breaking point is approached, the adjustments must be made more carefully and more slowly. Record the dial reading when the ring detaches from the surface.

(*d*) Make at least two measurements. Additional measurements shall be made if indicated by the over-all variation obtained, the total number of readings to be determined by the magnitude of that variation.

(*e*) Record the temperature of the solution and the age of the surface at the time of testing. Since the submerging of the ring (Paragraph (*b*)) may constitute a significant disturbance of the surface, take the age as the elapsed time between submersion and breakaway of the ring. The accuracy of this time observation may be indicated in the usual manner. In most cases an accuracy of ±5 sec is reasonable, and sufficient for this method.

Calculation and Report

6. (*a*) The dial reading, obtained from a measurement carried out in the foregoing manner with a calibrated instrument, is actually the pull per linear centimeter on the ring (both inner and outer circumferences being considered) at the break-point, expressed in dynes. This value, called the uncorrected surface tension, must be multiplied by a correcting factor, F, to give the corrected surface tension. F is a function of the contours of the liquid surface in the neighborhood of the ring at the instant of breakaway. It can be numerically specified in terms of R, the mean radius, in centimeters, of the ring; r, the radius, in centimeters, of the wire from which the ring is made; and V, the maximum volume of liquid elevated above the free surface of the liquid. For liquids of low surface tension, such as surface-active agents, F is, in general, appreciably less

than unity. It must, therefore, be ascertained and applied. Values of F in terms of two compounded parameters, $\frac{R^3}{V}$ and $\frac{R}{r}$ have been compiled and tabulated by Harkins and Jordan.[4] In order to look up F in the tables, the values of these two parameters must be calculated. Values for R and r are furnished by the manufacturer with each ring. The value of V is calculated from the following equation:

$$V = \frac{M}{D - d}$$

where:

M = weight of liquid raised above free surface of the liquid,
D = density of liquid, and
d = density of air saturated with vapor of the liquid.

To calculate M, multiply the tensiometer dial reading by the factor which converts this reading into grams pull on the ring, as calculated in Section 4 (*c*). The factor D can be measured by the usual procedures, and the value d can be obtained from published data. The corrected surface tension in dynes per centimeter is obtained by multiplying the uncorrected surface tension value by F.

(*b*) Unless specified, the surface tension values reported shall be corrected values. Report also the temperature at which the measurement was made. If it is desired to report the surface tension value of an aqueous solution at some standard temperature, for example, 25 C, and the measurement was actually made at a temperature with about 3 C of this value (that is, 22 to 28 C), a correction factor of 0.14 dynes per cm per deg Cent may be used. Subtract this correction factor from the surface tension when the temperature of the test is lower than the reported temperature, and add it to the surface tension when the temperature of the test is higher than the reported temperature. This value for the correction factor is not valid for nonaqueous liquids, and should be used only where the solvent is preponderantly water.

METHOD B. INTERFACIAL TENSION

Procedure

7. Determine interfacial tension as described in Section 5 for surface tension with the following modifications:

(*a*) The ring is always moved from the aqueous side of the interface through to the nonaqueous side. With liquids lighter than water, it is accordingly possible to use the precision tensiometer as well as the interfacial tensiometer. With liquids heavier than water, where the ring must be pushed downward, the interfacial tensiometer should be used.

(*b*) Fresh solutions and a freshly cleaned ring shall be used for each determination.

(*c*) When operating with a liquid heavier than the aqueous solution, the two-layer system shall be placed in the sample vessel and the ring placed in the upper (aqueous) layer. The measurement shall be made by turning the torsion wire counterclockwise and simultaneously keeping the ring system in the zero position, as in the measurement of surface tension, until the ring breaks through the interface.

(*d*) When operating with a liquid (oil) lighter than the aqueous solution, the aqueous solution shall be first placed in the sample vessel and the ring immersed therein. The oil shall then be carefully poured on top of the aqueous solution to form the two-layer system. Contact between the oil and the ring should be avoided during this operation. After allowing sufficient time for the interfacial tension to come to its equilibrium value (Note), the measurement shall be made in the same manner as that used for measuring surface tension.

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[4] W. D. Harkins and H. F. Jordan, "A Method for Determination of Surface and Interfacial Tension from the Maximum Pull on a Ring," *Journal Am. Chemical Soc.*, Vol. 52, p. 1751 (1930). These tables are also published in "Physical Methods of Organic Chemistry," Interscience Publishers, Inc., New York, N. Y., Vol. 1, pp. 182 to 184 (1945).

NOTE.—Since the interfacial energy of a newly formed liquid - liquid interface generally requires some time to reach its equilibrium value, it is advisable to wait at least 5 min after the interface is formed before taking a measurement.

Calculation and Report

8. (*a*) As in the case of surface tension, a correction factor, *F*, must be multiplied by the dial reading (pull on the ring in dynes) in order to obtain the corrected value for interfacial tension. Values for *F* have been published by Zuidema and Waters.[5] The factor *F* is, in this case, a function of the densities of the two liquids as well as of *R* and *r*, the radius of the ring and that of the wire respectively.

(*b*) Unless specified, interfacial tension values reported shall be corrected values. The nature of the nonaqueous liquid (oil) used in the determination shall be reported and adequately specified. The temperature at which the determination was made also shall be reported. In contrast to surface tension values, interfacial tension values cannot adequately be corrected for small temperature deviations by means of a simple formula.

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[5] H. H. Zuidema and G. W. Waters, "A Ring Method for Determination of Interfacial Tension," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 13, p. 312 (1941).

APPENDIX II

PROPOSED METHOD OF TEST FOR RINSING PROPERTIES OF METAL CLEANERS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. This method of test is designed to provide a reproducible laboratory means for determining the ease and thoroughness of rinsing of cleaning compositions, when applied to metal surfaces.

Test Specimens

2. The test specimens shall consist of 2 by 4-in. panels (the thickness being relatively unimportant) of ferrous or other metal agreed upon, whose condition and finish shall be specified. Duplicate panels shall be tested.

Precleaning Test Specimens

3. (*a*) Make ready the following precleaning materials for removal of soil present on the metal surface prior to test:

(*1*) Place 200 ml of carbon tetrachloride or trichloroethylene in a 250-ml beaker and maintain at room temperature.

(*2*) Prepare a vapor degreasing bath by heating 150 to 200 ml of carbon tetrachloride or trichloroethylene in a 1-liter beaker, the degree of vaporization being controlled to permit vapor-degreasing of the specimens when held in the beaker; or, alternatively, provide a wash bottle containing either of these solvents at room temperature.

(*3*) Maintain a 250-ml beaker of either anhydrous methanol or isopropanol at 50 C.

(*4*) Maintain a 250-ml beaker of distilled water at 50 C.

(*5*) Maintain a 250-ml beaker of redistilled acetone at room temperature.

(*6*) Place a small swab of fresh absorbent cotton in each of the beakers (Items (*1*) to (*5*)).

(*b*) Immediately prior to their use in the test, clean the test specimens as follows:

(*1*) Immerse the test specimens in the beaker of carbon tetrachloride or trichloroethylene (Paragraph (*a*)(*1*)) and immediately swab the surfaces of the individual specimens thoroughly, using clean forceps to hold both the cotton swab and the test specimen.

(*2*) Shake off excess solvent and either transfer the specimen to the vapor degreasing bath (Paragraph (*a*)(*2*)) long enough to observe the vapor completely covering and condensing on the specimen, or thoroughly wash the specimen with a stream of fresh solvent from the wash bottle.

(*3*) Swab the specimens separately in the beaker of alcohol (Paragraph (*a*)(*3*)) and shake free from excess alcohol.

(*4*) Transfer the specimens to the beaker of distilled water (Paragraph (*a*)(*4*)). Swab carefully and shake free from excess water.

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-12 on Soaps and Other Detergents. Published as information, June, 1952.

(5) Immerse the specimens separately several times in the beaker of acetone (Paragraph *(a)(5)*), shake free from acetone, and place them in another beaker, spacing the specimens for maximum exposure of surface area. Allow the specimens to air dry.

Concentration of Test Solution

4. *(a)* In the absence of the manufacturer's recommendations, test the specimens in solutions of the cleaner of the volume prescribed, and at solution concentrations of 0.25, 0.5, 1.0, 4.0, and 8.0 per cent by weight made up from stock solutions which shall be freshly prepared in 2000-g quantities. If the cleaner is not soluble to the extent noted in the stock solutions indicated, transfer a weighed quantity of the cleaner to a graduate and make up to volume. Some cleaners may contain rosin, or rosin soap, and with these a boiling period of 30 min will be necessary.

(b) When the manufacturer's recommendations are available, make the test at the following relative concentrations (based on the average concentrations suggested), recording the percentages these represent:

One half the concentration recommended,
The concentration recommended, and
Twice the concentration recommended.

Procedure

5. *(a)* Immerse the panels for 5 min in a beaker of the cleaning bath at the temperature of operation recommended by the manufacturer, or if this is not available, at 70 C. Remove the panels, suspend flat at an angle of 45 deg, and allow to dry.

(b) As soon as the panels are fully dry, suspend each panel in about 1 liter of distilled water at 70 ± 2 C for 3 min, withdrawing the panel slowly once each minute. Repeat this process with a fresh sample of distilled water at 70 C. Remove the panels and allow to dry at an angle of 45 deg as before. As soon as dry, observe the panels for any evidence of residue.

(c) Add a drop of USP alcohol to the panel surface, allow to evaporate, and observe for any evidence of a white deposit.

(d) Immerse the panels in running tap water, remove, and observe for water break.

Report

6. Report the presence or absence of residue by observation (Section *5(b)*) and by the alcohol drop procedure Section *5(c)*. Report the presence or absence of water break.

APPENDIX III

PROPOSED METHOD OF TEST FOR BUFFERING ACTION OF METAL CLEANERS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. This method describes a procedure for determining the buffering action of metal cleaners.

Definitions

2. (*a*) *Buffer Action.*—The resistance of a solution to change in pH.

(*b*) *Buffering Capacity.*—The ability of an alkaline solution to absorb acidic material without marked change in pH.

(*c*) *Buffer Index.*—The milliliters of 0.5 *N* hydrochloric acid required to decrease the initial pH to one of the following buffer ranges agreed upon by the purchaser and the seller:

(*1*) From initial pH of a solution to pH of 12.0,

(*2*) From pH 12.0 (or initial pH if between 11 and 12) down to pH 11.0, and

(*3*) From pH 11.0 down to pH 10.0.

Procedure

3. (*a*) Prepare 500 ml of a solution of 3.75 g (1 oz per gal) of the cleaner in distilled water.

(*b*) Transfer 100 ml of the solution at 25 ± 1 C to a 400-ml beaker.

(*c*) Determine the initial pH in accordance with the Tentative Method for Determination of the pH of Aqueous Solutions with the Glass Electrode (ASTM Designation: E 70),[2] using the high pH (low sodium-error) electrode.

(*d*) Add 1.0-ml increments of 0.5 *N* HCl to the solution. Bring the solution to equilibrium after each acid addition, and record the pH. Add further 1.0-ml increments of 0.5 *N* HCl, and record the corresponding pH values. Terminate the additions of HCl at a pH of 9.

Calculations

4. (*a*) Plot the curve for pH *versus* aliquots of 0.5 *N* HCl.

(*b*) Calculate the buffer index as follows:

Buffer index = ml of 0.5 *N* HCl to reduce pH to 10

or

Buffer index =

(*1*) ml of 0.5 *N* HCl to reduce initial pH to 12.0

(*2*) ml of 0.5 *N* HCl to reduce pH from 12 to 11

(*3*) ml of 0.5 *N* HCl to reduce pH from 11 to 10

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-12 on Soaps and Other Detergents. Published as information, June, 1952.

[2] 1949 Book of ASTM Standards, Parts 4, 5, and 6.

APPENDIX IV

PROPOSED METHOD OF TOTAL IMMERSION CORROSION TEST FOR SOAK TANK METAL CLEANERS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. (*a*) This method of test is intended as a means of determining the corrosive effects of soak tank metal cleaners on all metals other than aluminum and its alloys, under conditions of total immersion, by quantitative measurement of weight change or by qualitative visual determination of change. The test is designed for the determination of the effects of the cleaner on metals being cleaned, and is not for determination of the life of the cleaner or of the containing equipment.

(*b*) When the test is used to assist in the choice of material for a specific use, the test conditions should simulate the conditions of use as closely as practicable.

(*c*) Where no further processing subsequent to cleaning is indicated, a test for the effect of residual cleaner on the corrosion behavior of the material may be required.

Apparatus

2. (*a*) *Test Tubes*, of a suitable material, 38 mm in diameter by 300 mm in length, having a capacity of about 300 ml shall be provided. The tubes shall be chosen so that the specimens will remain fully immersed during the test, and the ratio of area of immersed metal to the volume of solution will be as prescribed in Section 5(*a*), with sufficient space provided for foam formation.

(*b*) *Condensers.*—Allihn-type condensers, having jackets 200 to 250 mm in length shall be provided, except that condensers will not be required for tests run at room temperature.

(*c*) *Stoppers or Joints.*—The connection between test tube and condenser optionally may be either standard-taper joints or rubber stoppers preboiled in aqueous caustic soda to remove free sulfur, and boiled in a sufficient number of changes of distilled water until neutral.

(*d*) *Constant - Temperature Device.* — Any suitable means may be employed for maintaining the solutions actively at the boiling point for tests conducted at that temperature. For tests made at other temperatures, a suitable constant-temperature bath shall be provided to maintain the required temperature within ±2 F (1 C). For control testing at room temperature, it is suggested that the solution be maintained at 95 ± 2 F (35 ± 1 C), which, being slightly above most room temperatures, is easy to maintain by heat input.

(*e*) *Coating Apparatus* shall be provided suitable for producing a uniform film of cleaner on the surface of the test specimen, for testing the effects of residual cleaner on the surfaces of cleaned metals (Section 8).

(*f*) *Humidity Chamber* shall be provided for exposing the contaminated specimens at 90 per cent relative humidity as specified in Section 8 (*c*).

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-12 on Soaps and Other Detergents. Published as information, June, 1952.

Test Specimens

3. The test specimens shall be identical in composition, metallurgy, and surface finishing, with the conditions of the metal at the stage where cleaning will be applied in practice. The specimens shall have an area between 0.300 and 0.375 sq dm, and a length not to exceed 200 mm. (A specimen 18 by 85 by 1 mm in thickness would have an area of 0.327 sq dm.) At least two, and preferably four, replicates shall be tested in each concentration of cleaner solution prescribed in Section 5 (*b*). The number of replicates under test shall be recorded.

Precleaning Test Specimens

4. (*a*) Make ready the following precleaning materials for removal of soil present on the metal surface prior to corrosion testing:

(*1*) Place 200 ml of carbon tetrachloride or trichloroethylene in a 250-ml beaker and maintain at room temperature.

(*2*) Prepare a vapor degreasing bath by heating 150 to 200 ml of carbon tetrachloride or trichloroethylene in a 1-liter beaker, the degree of vaporization being controlled to permit vapor degreasing of the specimens when held in the beaker; or, alternatively, fill a wash bottle containing either of these solvents at room temperature.

(*3*) Maintain a 250-ml beaker of either anhydrous methanol or isopropanol at 122 F (50 C).

(*4*) Maintain a 250-ml beaker of distilled water at 122 F (50 C).

(*5*) Maintain a 250-ml beaker of redistilled acetone at room temperature.

(*6*) Place a small swab of fresh absorbent cotton in each of the beakers (Items (*1*) to (*5*)).

(*b*) Immediately prior to their use in the test, clean the test specimens as follows:

(*1*) Immerse the test specimens in the beaker of carbon tetrachloride or trichloroethylene (Paragraph (*a*)(*1*)) and immediately swab the surfaces of the individual specimens thoroughly, using clean forceps to hold both the cotton swab and the test specimen.

(*2*) Shake off excess solvent and either transfer the specimen to the vapor degreasing bath (Paragraph (*a*)(*2*)) long enough to observe the vapor completely covering and condensing on the specimen, or thoroughly wash the specimen with a stream of fresh solvent from the wash bottle.

(*3*) Swab the specimens separately in the beaker of alcohol (Paragraph (*a*)(*3*)) and shake free from excess alcohol.

(*4*) Transfer the specimens to the beaker of distilled water (Paragraph (*a*)(*4*)). Swab carefully and shake free from excess water.

(*5*) Immerse the specimens separately several times in the beaker of acetone (Paragraph (*a*)(*5*)), and shake free from acetone.

(*6*) If the specimens are to be weighed, dry in a vacuum desiccator or in a low-temperature oven at 100 F (37.7 C).

Test Conditions

5. (*a*) *Ratio of Area of Immersed Metal to Volume of Solution.*—The ratio of the area of the immersed metal to the volume of solution shall be less than 1.5 sq dm per liter of solution. (A specimen 18 by 85 by 1 mm in thickness would require 220 ml of solution, and a specimen having an area of 0.375 sq dm would require 250 ml of solution.) Use fresh solution for each set of replicates and record the ratio used.

(*b*) *Solution Concentration:*

(*1*) In the absence of the manufacturer's recommendations, test the specimens in solutions of the cleaner of concentrations of 0.25, 0.5, 1.0, 4.0, and 8.0 per cent by weight, made up from stock solutions which shall be freshly prepared in 2000-g quantities. Boil the solutions for 30 min unless otherwise specified. In case the cleaner is not soluble to the extent noted in the stock solutions indicated, record this fact, but nevertheless continue the test with the specified total amounts of cleaner present in the test tubes. A blank test of either two or four replicates shall be made in freshly boiled distilled water.

(*2*) When the manufacturer's recommendations are available, make the test at the following relative concentrations (based on the average concentrations suggested), recording the percentages these represent:

One half the concentration recommended,
The concentration recommended, and
Twice the concentration recommended.

Make a blank test of either two or four replicates in freshly boiled distilled water, submitting them otherwise to exactly the same procedure followed for the specimens immersed in cleaner solution.

(*c*) *Water.*—The water used in preparing the water-soluble cleaner solutions shall be freshly boiled distilled water.

(*d*) *Temperature.*—In the absence of manufacturer's recommendations, make the test at the boiling point of the solution. With available recommendations, make the test at 20 ± 2 F (11 ± 1 C) below and 20 ± 2 F (11 ± 1 C) above the average recommended temperature, or at the boiling point of the solution if it is lower. Record the temperature of the test in any case.

Procedure for Quantitative Weight Loss Test

6. (*a*) Weigh the cleaned dry test specimens to the nearest 0.001 g.

(*b*) Transfer the specimens individually to test tubes containing the preheated cleaner solutions, using only one specimen per tube. Attach the tubes to reflux condensers and maintain at the required temperature, adding a small piece of unglazed porcelain to prevent bumping. Expose for a period of 2 hr. Other exposure periods may also be observed where appropriate.

(*c*) Remove the strips at the end of the exposure period and proceed as follows:

(*1*) Hold the specimen in forceps and rinse thoroughly in a 1-liter beaker into which tap water is flowing rapidly.

(*2*) Rinse thoroughly in distilled water at room temperature.

(*3*) Rinse with a stream of acetone from a wash bottle. Shake free from acetone and dry.

(*4*) Examine for, and record any of the following visible changes in comparison with the original uncleaned specimen:

Discoloration,
Dulling,
Etching,
Presence of accretions and relative amounts and areas,
Types of pitting—wide, medium, or narrow, and
Presence of selective or localized attack.

(*5*) Remove corrosion products. (Methods of removal of corrosion products from different metals are given in Appendices I and II.)

(*6*) Rinse and dry as indicated in Items (*2*) and (*3*).

(*7*) Weigh to the nearest 0.001 g.

Procedure for Qualitative Surface Corrosion Test

7. Proceed as for the quantitative weight loss test, except that drying

and weighing the specimens before the test shall be omitted, and the removal of corrosion products may be dispensed with unless the corrosion is severe enough to obscure observation.

Procedure for Residual-Cleaner Corrosion Test

8. Where it is desired to determine the effect of residual cleaner on the corrosion behavior of the materials tested, make the following test:

(*a*) Immerse clean test panels in solutions of the cleaner of the following concentrations and temperatures, allowing the panels to come to the temperature of the solution, and then slowly withdrawing them by a suitable apparatus such as a Fisher-Payne Dip Coater in such a manner as to leave a thin uniform coating of cleaner on the surface of the specimen:

(*1*) The concentration of the test solution shall be one tenth the concentration recommended by the manufacturer, or 0.5 per cent by weight when no concentration is recommended.

(*2*) The temperature of the solution shall be that recommended by the manufacturer or, in the absence of any recommendation, the boiling point of the solution.

(*b*) Dry specimens at a moderate temperature (about 212 F (100 C)).

(*c*) Expose the dried specimens to 90 per cent relative humidity at 95 F (35 C) for one week.

(*d*) Treat the specimens as indicated in Section 6 (*c*) (*4* to *7*).

Report

9. (*a*) *Quantitative Weight Loss Test.*—Report the following data for each test performed:

(*1*) Temperature,
(*2*) Specimens, size and number,
(*3*) Cleaner concentrations,
(*4*) Metal, alloy, surface treatment, and metallurgical state,
(*5*) Ratio of surface area to volume of solution,
(*6*) Type of cleaner and other conditions of test peculiar to type,
(*7*) Weight loss in milligrams per square decimeter per hour,
(*8*) Range in weight loss values, and
(*9*) Appearance before and after removal of corrosion products with regard to the following:
  Discoloration,
  Dulling,
  Etching,
  Presence of accretions and relative amounts and areas,
  Type of pitting—wide, medium, or narrow, and
  Presence of selective or localized attack.

(*b*) *Qualitative Surface Corrosion Test.*—Report the same information as for the quantitative weight loss test (Paragraph (*a*)), except to omit Items (*7*) and (*8*).

SUPPLEMENT I

METHOD FOR ELECTROLYTIC CLEANING OF CORROSION TEST SPECIMENS AFTER EXPOSURE

A1. (*a*) After scrubbing to remove loosely attached corrosion products, treat the specimen as a cathode in hot, dilute sulfuric acid under the following conditions:

Test solution	sulfuric acid (5 per cent by weight)
Inhibitor	2 ml organic inhibitor per liter of solution
Anode	carbon
Cathode	test specimen
Cathode current density	20 amp per sq dm (6.5 amps per 0.327 sq dm)
Temperature	165 F (74 C)
Exposure period	3 min

(*b*) After the electrolytic treatment, scrub the specimens, while wet, with a stiff bristle brush. The weight losses of specimens 0.5 sq dm in area, treated by the method described, have been found to be of the order shown in Table I.

(*c*) It should be noted that this electrolytic treatment may result in the redeposition of adherent metal from reducible corrosion products, and thus lower the apparent weight loss. However, general experience has indicated that in most cases of corrosion in liquids the possible errors from this source are not likely to be serious. Instead of using 2 ml of any proprietary inhibitor, about 0.5 g per liter of such inhibitors as diorthotolyl thiourea, quinoline ethiodide, or betanaphthol quinoline may be used.

SUPPLEMENT II

CHEMICAL METHODS FOR CLEANING CORRODED SPECIMENS WITHOUT USE OF ELECTRIC CURRENT

A2. (*a*) *Copper and Nickel Alloys.*—Dip for 2 to 3 min in hydrochloric acid (1:1) or sulfuric acid (1:10) at room temperature. Scrub with a bristle brush under running water, and dry.

(*b*) *Tin Alloys.*—Dip for 10 min in boiling trisodium phosphate solution (15 per cent by weight) prepared from material conforming to the Standard Specifications for Trisodium Phosphate (ASTM Designation: D 538).[2] Scrub with a bristle brush under running water, and dry.

(*c*) *Lead Alloys.*—Dip for 10 min in boiling acetic acid (1 per cent by volume). Brush with a bristle brush under running water, and dry.

(*d*) *Zinc.*—Immerse the specimens in warm (140 to 180 F) ammonium chloride (10 per cent by weight) for several min. Rinse in water, and scrub with a soft brush. The accumulation of corrosion products is removed almost completely by this treatment. Then immerse the specimens for 15 to 20 sec in a boiling solution of chromic acid (5 per cent by weight) and silver nitrate (1 per cent by weight). Rinse in hot water, and dry.

NOTE.—In making up the chromic acid solution, it is advisable to dissolve the silver nitrate separately and add it to the boiling chromic acid to prevent excessive crystallization of the silver chromate. The chromic acid must be free from sulfate to avoid attack on the zinc.

(*e*) *Magnesium Alloys.*—Clean for approximately 1 min in chromic acid (20 per cent by weight) to which has been added, with agitation, 1 per cent by weight of silver nitrate in solution form. Operate the bath at 200 to 212 F.

TABLE I.—WEIGHT LOSSES OF 0.5-SQ DM SPECIMENS SUBJECTED TO ELECTROLYTIC CLEANING TREATMENT.

Material	Total Weight Loss, g
Copper-nickel-zinc (75-20-5)	0.0000
Brass (admiralty)	0.0001
Brass (red)	0.0000
Brass (yellow)	0.0002
Bronze (phosphor, 5 per cent tin)	0.0000
Bronze (silicon)	0.0002
Bronze (cast) (85-5-5-5)	0.0010
Copper	0.0001
Copper-nickel (70-30)	0.0000
Iron and steel	0.0003
Nickel-molybdenum-iron (60-20-20)	0.0004
Nickel-chromium-iron (80-13-7)	0.0000
Lead (chemical)	0.0030
Nickel-Copper (70-30)	0.0000
Nickel	0.0011
Stainless steel	0.0000
Tin	0.0003
Magnesium and zinc	too high to be useful

(*f*) ***Iron and Steel.***—Clean for 2 to 3 min by immersion in a boiling solution of ammonium citrate (10 per cent by weight).

(*g*) ***Stainless Steel.***—Clean for 5 min by immersion in a solution of nitric acid (30 per cent by volume) at a temperature of 120 to 130 F.

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[2] 1949 Book of ASTM Standards, Part 5.

REPORT OF COMMITTEE D-13

ON

TEXTILE MATERIALS*

Committee D-13 on Textile Materials held two 3-day meetings during the year, both of them in New York City. The General Session at the October meeting was devoted to reports from members of the American Delegation to the meeting in England in June, 1951, on the work of the Technical Committee on Textiles of the International Organization for Standardization; and to the Second Award of the Harold DeWitt Smith Memorial Medal to Professor Edward R. Schwarz. The third award of the medal was made in 1952 to Dr. Frederic Bonnet at the March meeting. The first award of the medal was made to H. F. Schiefer at the March, 1950, meeting.

The improved ASTM Cotton Yarn Appearance Standards, for which a task group in Subcommittee A-1 Section II, headed by Mr. J. M. Cook, is responsible have been in great demand during the year both in the U. S. and abroad.

A Joint ASTM-AATCC Committee on Textile Test Methods has been appointed to insure prompt and effective coordination of the methods of the two organizations. ASTM is represented by P. J. Smith, H. J. Ball, and W. D. Appel; AATCC by H. W. Stiegler, J. R. Bonnar, and L. S. Little.

The following appointments of subcommittee officers were approved by the Advisory Committee during the year: W. Blake Lane, vice G. K. Lake, as chairman of A-1, Section III with H. L. Pratt as secretary; F. F. Kobayashi, vice Edwin Wilkinson, as secretary of A-3, Section III; E. M. Lynch, Jr., vice B. I. Bertelsen, as chairman of A-3, Section V, and P. F. Flamm as secretary of B-2, vice F. D. Pilgrim. Past Chairman H. J. Ball was elected Honorary Chairman.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. D. Appel.
First Vice-Chairman, S. J. Hayes.
Second Vice-Chairman, R. T. Kropf.
Secretary, W. H. Whitcomb.

RECOMMENDATIONS AFFECTING STANDARDS

Committee D-13 is presenting for publication 8 new tentatives and is recommending the revision of 9 tentatives, tentative revisions in 2 standards, adoption as standard of several definitions, 4 tentatives, and tentative revisions of 5 standards, immediate revision of 6 standards, revision of 1 standard with reversion to tentative, withdrawal of one term, editorial change in 1 tentative, and the reaffirmation of 8 standards.

The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.

All other tentatives not specifically referred to are being actively studied by the respective sponsoring subcommittees.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee A-1 on Cotton and Its Products (B. L. Whittier, chairman):

Section I on Cotton (G. S. Buck, Jr., chairman) is studying methods of test for various properties of cotton with a view to setting up separate standards for each property.

Section II on Cotton Yarns and Threads (W. R. Marsden, chairman) is continuing its work on revision of the Methods of Testing and Tolerances for Cotton Yarns (D 180 – 49 T), and for Cotton Sewing Thread (D 204 – 42).

Section III on Cotton Woven Fabrics (W. B. Lane, chairman) is undertaking a complete review of the standards under its jurisdiction.

Subcommittee A-2 on Man-Made Organic-Base Fibers and Their Products (A. M. Tenney, chairman):

Section I on Spun and Continuous Filament Man-Made Organic-Base Yarns (J. K. Frederick, Jr., chairman) is holding up on its study of the methods of testing these yarns pending the adoption of general methods of testing yarns. The section is studying the commercial regains for these yarns and also an ISO report concerning a systematic restriction of yarn numbers. The combining of Methods D 258 – 50 T on Continuous Filament Yarns and Methods D 507 – 44 on Spun Yarn is under consideration.

Subcommittee A-3 on Wool and Its Products (Werner von Bergen, chairman):

Section I on Wool (O. P. Beckwith, chairman) is continuing its study of wool testing with particular reference to determination of fineness, tensile strength, moisture, and alkali solubility.

Section III on Woolen and Worsted Yarns (H. R. Anderson, chairman) is working on a revision and consolidation of the Specifications and Methods of Test for woolen Yarns (D 403 – 48 T), and for Worsted Yarns (D 404 – 48 T).

Section V on Woolen and Worsted Fabrics (E. M. Lynch, Jr., chairman) is studying shrinkage and fiber analysis of blends.

Subcommittee A-4 on Asbestos and Its Textile Products (F. S. Mapes, chairman) is studying the significance of tests of asbestos materials, and the analysis of asbestos textiles with particular reference to cotton and fiberglass.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (S. J. Hayes, chairman) is studying methods of determining moisture.

Subcommittee A-7 on Ultimate Consumer Textile Products (A. F. Tesi, chairman) is continuing its studies of test methods for antiseptic finishes, snag resistance of hosiery, pilling of fabrics, slide fasteners, and elastic fabrics.

Subcommittee A-8 on Glass Fiber and Its Products (F. A. Mennerich, chairman) is continuing its study of methods for determining spread and build-up of glass yarns for wrap and braided covers of wires.

Subcommittee A-9 on Tire Cord and Fabrics (F. S. Kennedy, chairman) is continuing its work on the revision of Methods of Tests and Tolerances for Cotton Tire Cord (D 179 – 46 T), and for Rayon Tire Cord (D 885 – 46 T), and on air-actuated clamps.

Subcommittee A-10 on Nonwoven Fabrics (R. R. Stevens, chairman; G. B. Harvey, vice-chairman):

Section I on Felt (R. R. Stevens, chairman) is continuing its work on measurement of stiffness of felts and thickness of cut parts.

Section II on Bonded Fabrics (G. B. Harvey, chairman) is continuing its work on water absorbency, fire resistance, abrasion resistance, air permeability, laundering and dry cleaning, flexural rigidity, and tear resistance.

Subcommittee A-11 on Pile Fabrics (E. A. Leonard, chairman) is working on light-fastness standards, resistance to abrasion, fire resistance, resistance to insect damage, alkali solubility, effect of shampooing on color, and moisture content of kraft cord.

Subcommittee B-1 on Test Methods (W. M. Scott, chairman) is continuing its study of dimensions of jaws for the grab test, general methods of testing yarns and fabrics, crease resistance, identification of finishes, analysis of mixtures containing dynel, or orlon, or viscose and cotton, and resistance to fire. It is also studying evenness of yarns, thickness of fabrics, evaluation of fibers in bulk form, thermal transmission, and colorfastness to washing.

In recognition of the growing interest in general methods of test for fibers, yarns, and fabrics, action was taken on May 14, 1952, to establish the following five subdivisions under Subcommittee B-1: (1) Fiber Tests, (2) Yarn Tests, (3) Fabric Tests, (4) Chemical Methods, and (5) Performance Tests.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman) is continuing its work of developing standard and tentative definitions, and designation of yarn construction. It is also considering an expansion of the Glossary of Defects in Woven Fabrics.

Subcommittee B-5 on Sampling, Presentation and Interpretation of Data (J. C. Hintermaier, chairman) is continuing its study of the sampling of part wool blankets for determining fiber content. The subcommittee is planning a technical papers session for the fall meeting of Committee D-13 in 1953.

This report has been submitted to letter ballot of the committee, which consists of 351 members; 147 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. D. APPEL,
Chairman.

W. H. WHITCOMB,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-13 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative General Methods of:

Sampling Cotton Fibers for Testing (D 1441 – 52 T).

Tentative Method of:

Test for Fiber Weight Per Unit Length and Maturity of Cotton Fibers (Array Method) (D 1442 – 52 T).

Tentative Recommended Practice for:

Designation of Yarn Construction (D 1244 – 52 T).

Revision of Tentative General Methods of:

Testing Cotton Fibers (D 414 – 49 T).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the new and revised tentatives appear in the 1952 Book of ASTM Standards, Part 7.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentatives covering textile materials, which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1949 Book of ASTM Standards, Part 5, or in the 1950 and 1951 Supplements to Book of ASTM Standards, Part 5, and in the Committee D-13 compilation of ASTM Standards on Textile Materials.

NEW TENTATIVES

Committee D-13 recommends the following five methods and three tolerances for publication as tentative, as appended hereto.[1]

Tentative Methods of:

Testing Twine (From Bast and Leaf Fibers)
Sampling and Testing Staple Length of Wool in the Grease
Test for Shrinkage in Laundering of Cotton Knit Fabrics
Test for Shrinkage in Laundering of Rayon Knit Fabrics
Test for Flammability of Clothing Textiles, developed in cooperation with the American Association of Textile Chemists and Colorists

Tentative Tolerances for:

Acetate Yarn
Rayon Yarn
Nylon Yarn

REVISION OF TENTATIVES

Tentative Definition of Terms Relating to Textile Materials (D 123 – 51 T):

The committee recommends that this tentative be revised by the addition of a number of new and revised definitions, as appended hereto.[2] These definitions were prepared by Subcommittee B-2.

Tentative Specifications and Methods of Test for Asbestos Yarns (D 299 – 51 T):

On recommendation of Subcommittee A-4, it is proposed that Section 13 on asbestos content be revised by the addition of the following Paragraph (*b*) designating the present section as Paragraph (*a*):

> (*b*) In making asbestos content determinations on asbestos yarns reinforced with continuous filament glass yarns, such insertion shall be removed before making the determination. The organic content is to be computed on the basis of the oven-dry weight of the glass reinforced yarn previous to removal of the glass yarn insert.

Tentative Methods of Test for Resistance of Textile Fabrics to Water (D 583 – 50 T):

On recommendation of Committee B-1, it is proposed that these methods be revised as follows:

Section 8.—Designate as Paragraph (*a*) the first 22 lines through "Fig. 2". Designate as Paragraph (*b*) the remainder of the section.

Add as a new Paragraph (*c*) the following: "(*c*) Report the spray rating for each specimen tested."

Section 11.—Change to read as follows:

> 11. Cut the test pieces 8 by 8 in. on a 45-deg. bias and remove the loose corner yarns to

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[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 5.

[2] The revised tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 5.

prevent subsequent fraying. Five pieces shall constitute one specimen. Test two specimens together to evaluate the dynamic absorption of a single sample.

Section 12.—Change "Specimens" to "pieces" throughout this section. Change Paragraph (*b*) to read as follows: "(*b*) Repeat the squeezing, blotting, and weighing procedure described in Paragraph (*a*) for the second set of five pieces."

Substitute for Paragraph (*c*) the following Paragraphs (*c*) and (*d*):

(*c*) Calculate the dynamic absorption for each specimen as follows:

Dynamic absorption, per cent

$$= \frac{\begin{matrix}\text{Final wt} \\ \text{of specimen}\end{matrix} - \begin{matrix}\text{original wt} \\ \text{of specimen}\end{matrix}}{\text{Original wt of specimen}} \times 100$$

(*d*) The dynamic absorption of the fabric shall be the average of the results obtained from the specimens tested and shall be reported to the nearest 1.0 per cent.

Section 14.—Substitute for Paragraph (*c*) the following Paragraphs (*c*), (*d*), and (*e*):

(*c*) As soon as possible after squeezing, reweigh the specimen to the nearest 5 mg.

(*d*) Calculate the static (immersion) absorption for each specimen as follows:

Static absorption, per cent

$$= \frac{\begin{matrix}\text{Final wt} \\ \text{of specimen}\end{matrix} - \begin{matrix}\text{original wt} \\ \text{of specimen}\end{matrix}}{\text{Original wt of specimen}} \times 100$$

(*e*) The static absorption of the fabric shall be the average of the results obtained from the specimens tested and shall be reported to the nearest 1.0 per cent.

Section 17.—Continue to designate as Paragraph (*a*) the text ending with the words "within 1 min" in line 18. Designate as Paragraph (*b*) the following: "(*b*) Determine the increase in the weight of the blotter during the test period." Delete the last two sentences and add as Paragraph (*c*) the following:

(*c*) The penetration of the fabric shall be the average increase in weight of the blotters from the specimens tested and shall be reported to the nearest 0.1 g. Report penetrations of over 10.0 g as 10 + g. Do not re-use the blotter.

Section 20.—Designate as Paragraph (*a*) the text of the present section through line 17 and ending with the sentence "Start a timing device concurrently." Delete the remainder of the text and substitute the following as Paragraphs (*b*) and (*c*):

(*b*) Measure the time required to collect 10 ml. of water in the graduated cylinder and record it to the nearest 1.0 sec.

(*c*) The drop penetration of the fabric shall be the average of the results obtained from the specimens tested and shall be reported to the nearest 1.0 sec.

Section 22.—In line 9 after the words "the rate of 1 cm per sec," insert the words "a vent to permit the air in the upper orifice plate to escape;". . . .

Section 23.—Designate as Paragraph (*a*) the text of the first 7 lines ending with "(Note 4)." Substitute for the remainder of the text the following Paragraph (*b*):

(*b*) Record the hydrostatic head (in parts of either centimeters or inches) at the first sight of water penetrating at a third place in the fabric.

Add as Paragraph (*c*) the following:

(*b*) The hydrostatic resistance of the fabric shall be the average of the results obtained from the specimens tested and shall be reported to the nearest 1.0 cm or 0.5 in., as required.

Section 26.—Designate as Paragraph (*a*) the first 9 lines of the text ending with the word "fabric." Designate the last sentence as Paragraph (*b*) and change to read as follows:

(*b*) Record the hydrostatic head (in parts of either centimeters or inches) at the first sight of water penetrating at a third place in the fabric.

Add the following and designate it as Paragraph (*c*):

(*c*) The hydrostatic resistance of the fabric shall be the average of the results obtained from the specimens tested and shall be reported to the nearest 1.0 cm or 0.5 in., as required.

Section 28.—Substitute the following:

28. The hydrostatic pressure test apparatus, shown in Fig. 8, shall be similar to that described in Section 22, Method I, except that introduction of the hydrostatic head at a rate of 1 cm per sec is not required. A cut-off valve or other suitable device shall be provided at the water inlet of the upper orifice plate for keeping the water from the specimen until the desired head is reached. No air shall be trapped in the hose between the reservoir and the cut-off valve. An outlet shall be provided in the upper orifice plate to permit the escape of air displaced by water entering the space above the clamped specimen.

Section 29.—Substitute the following:

29. (*a*) With the cut-off valve closed, clamp the test specimen (cut approximately 8 by 8 in.), face up, over the inverted conical well by means of a lever clamp. Adjust the water level to give the required hydrostatic head, as given below or otherwise specified:

(Use present table.)

(*b*) Simultaneously open the valve and start the timing. Measure the amount of water passing through the fabric during a 10-min. or other specified time interval and record its volume in milliliters.

(*c*) The water permeability of the fabric for the specified head and test interval shall be the average of the results obtained for the specimens tested and shall be reported to the nearest milliliter.

Tentative Method of Test for Small Amounts of Copper and Manganese in Textiles (D 377 – 50 T):

These methods have been extensively revised by Subcommittee B-1, as appended hereto.[2]

Tentative Methods of Testing and Tolerances for Cotton Yarns (D 180 – 49 T):

On the recommendation of Subcommittee A-1, it is proposed that Section 11 (*b*) be revised as follows, retaining present Notes 1 and 2:

(*b*) *Procedure.*—A sample of the yarn under test shall be wound upon a black board covering an area of approximately 5½ by 9½ in. with a designated traverse and compared with a photographic standard.

Tentative Methods of Testing and Tolerances for Continuous Filament Rayon and Estron Yarns (D 258 – 50 T):

On the recommendation of Subcommittee A-2, it is proposed that these methods be revised as follows:

Title.—Delete "and Tolerances," also substitute "acetate" for "estron."

Section 1.—Substitute "acetate" for "estron."

Section 2.—Delete Paragraphs (*c*) and (*n*) and reletter the remaining paragraphs accordingly.

Sections 3 to 6.—Delete these sections on tolerances since they are now superseded by the new Tentative Tolerances.

Add a new Section 3 on Tolerance as follows:

3. Tolerances for acetate, rayon, and nylon yarns appear in the Tentative Tolerances for Filament Acetate Yarns (ASTM Designation: D 1235), Tentative Tolerances for Filament Nylon Yarns (ASTM Designation: D 1236), and Tentative Tolerances for Filament Rayon Yarns (ASTM Designation: D 1237).

Sections 15 (e), 22, and 26 (c).—Substitute "acetate" for "estron" wherever it appears in these several sections.

Tentative Specifications and Methods of Test for Asbestos Lap (D 1061 – 51 T):

On the recommendation of Subcommittee A-4, it is proposed that these specifications be revised as follows:

Section 4.—Change the asbestos content requirements from their present form: namely,

Grade	Asbestos Content, per cent
Commercial Grade	75 to 80, excl.
Underwriters' Grade	80 to 85, excl.
Grade A	85 to 90, excl.

to read as follows:

Grade	Asbestos Content, per cent
Underwriters' Grade	80 to 85, excl.
Grade A	85 to 90, excl.
Grade AA	90 to 95, excl.
Grade AAA	95 to 99, excl.

Section 5.—In table following Grade A, add "AA and AAA" to indicate that the requirements for total iron content and magnetic rating of non-ferrous lap apply to all three grades.

Tentative Method of Test for Fastness of Colored Textiles to Light (D 506 – 50 T):

In cooperation with the American Association of Textile Chemists and Colorists, this method has been extensively revised by Subcommittee B-1 and is recommended for publication as tentative, as appended hereto.[2]

Tentative Recommended Practice for Planning Interlaboratory Testing of Textile Materials (D 990 – 49 T):

As a result of experience with this recommended practice for the past three years, it has been found desirable to simplify the presentation of the recommendations. It is accordingly proposed that this recommended practice be revised as appended hereto.[2]

TENTATIVE REVISIONS OF STANDARDS

Standard Specifications for Textile Testing Machines (D 76 – 49):

On recommendation of Subcommittee B-2, the following changes are recommended for publication as a tentative revision of this standard:

Section 2.—Change to read as follows:

2. Tension testing machines for use on textile materials may be generally classified as operating on one of the following three principles: (*1*) constant-rate-of-traverse (pendulum), (*2*) constant-rate-of-load, (*3*) constant-rate-of-specimen extension. The constant-rate-of-traverse and the constant-rate-of-load machines shall conform to the requirements of Sections 3 to 7, inclusive; the constant-rate-of-specimen-extension machines shall conform to Sections 4, 6(*a*), and 8.

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Section 3.—Designate the present Paragraph (*a*) as: "(*a*) *1.*" and add as an alternate method the following:

2.—Machines in the constant-rate-of-traverse class shall be operated at such a rate that the yarns break within 20 ± 3 sec from the time of the start of the test, unless otherwise specified.

Designate the present Paragraph (*b*) as: "(*b*) *1.*" and add as an alternate method the following:

2.—Machines in the constant-rate-of-load class shall be operated at such a rate that the yarn breaks within 20 ± 3 sec from the time of the start of the test, unless otherwise specified.

New Section.—Insert as a new Section 8 the following on Machine Operation for Constant-Rate-of-Specimen-Extension Tests, renumbering present Section 8 and subsequent sections accordingly:

8. (*a*) Machines in the constant-rate-of-specimen-extension class shall be power driven and shall be so operated that the straining rates used will conform to rates listed in Tables I and II.

TABLE I.—RATES OF CROSS-HEAD TRAVEL FOR YARN, MONOFILAMENT, AND SINGLE FIBER TESTS.

Break Elongation of Specimen, per cent	Rate of Cross-head Travel, per cent of initial specimen, length per min.
Under 8	10
8 to 100, incl.	60
Over 100	240

TABLE II.—RATES OF CROSS-HEAD TRAVEL FOR FABRICS.

Break Elongation of Specimen. per cent	Rate of Cross-head Travel. per cent of initial specimen, length per min.
Under 12	20
8 to 100, incl.	50
Over 90	200

NOTE.—Results observed for initial modulus and breaking strength depend upon the straining rate used. In borderline cases where one or two different straining rates could be used, the report shall, in every instance, state the exact straining rate used.

The straining rates listed in Tables I and II shall be held constant, except that at no time shall the dynamic response time of the recording mechanism of the machine be exceeded (see Paragraph (*c*)). If a change in the straining rate is required by this limitation, this fact shall be included in the report.

In the case of yarn or single filament testing where the standard specimen length specified for other types of machines cannot be used because of (*1*) the break elongation is greater than the machine can handle, (*2*) where the desired rate of elongation cannot be obtained on such lengths, a shorter specimen length of not less than 4 in. may be used; however, the straining rates used must conform to those listed in Table I. The actual specimen length used in these cases shall be included in the report.

In the case of single fiber testing, the specimen length shall be as large as practicable; however, the straining rates used shall conform to those listed in Table I.

In the case of fabric testing, the established specimen lengths shall be used, providing the straining rates used conform to those listed in Table II.

(*b*) The tolerance in load indication shall be not more than ±0.5 per cent of any given load range. The recording mechanism must return to its zero position within ±0.5 per cent of any given load range upon release of the load. The calibration of the weighing system should be determined by dead weighting, and the weights used in such a calibration should conform to ASTM Methods E 4 and they should be equal in weight to at least 10 per cent of any given full scale load, except where the full scale load is in excess of 200 lb. In such cases, the calibration should be determined by the procedures listed under ASTM Method E 4 or by the use of a proving ring as described in ASTM Method E 74.

(*c*) The dynamic response time of the recording mechanism is the limiting factor affecting the choice of a rate-of-elongation for testing. The rate-of-elongation should be so chosen that the maximum slope of any portion of the recorded curve shall not exceed one half of the slope of the maximum pen speed.

(*d*) The load weighing system, including the recording mechanism, must have a full scale pen response speed as fast as possible but in no case slower than 5 sec for full scale movement in either direction. In addition, the response time for pen deflections of less than full scale should be proportional to the fraction of full scale time represented by that deflection within a tolerance of 10 per cent of the full scale time.

(*e*) The tolerance on the rate of the pulling clamp movement shall be ±5 per cent of any given speed (see Paragraph (*a*)) at any point of its travel. The exact travel of the pulling clamp shall be measured to within ±1.0 per cent where the specimen elongation is calculated from the movement of the pulling clamp.

(*f*) The movement of the stationary clamp shall be restricted to within 0.005 in. for loads within the rated capacity of the machine. This movement may be measured by a cathetometer or by other precision methods of deflection measurement.

(*g*) The capacity of the tester shall be so selected that the break will occur at or above 30 per cent full scale of any given range.

(*h*) The maximum strength observed shall be recorded as the breaking strength, and the maximum elongation corresponding to the maximum strength shall be reported as the breaking elongation.

(*i*) In the cases where a portion of the specimen breaks before or after the point of maximum strength, this fact shall be indicated in the report.

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 49):

On the recommendation of Subcommittee A-4, the following changes are recommended as a tentative revision of this standard:

Section 4.—Change the asbestos content requirements to read the same as given above for Specifications 1061; also revise the note in this section to read as follows: "Note.—The 16 and 18 cut rovings are available only in the Underwriters' Grade; all other cuts are available in all four grades."

Section 5.—In the table following Grade A, add "AA and AAA" as in Specifications 1061.

Section 9.—Designate the present text as Paragraph (*a*) and add as Paragraph (*b*) the following:

> (*b*) In making asbestos content determinations on asbestos roving reinforced with continuous filament glass yarns, such insertion shall be removed before making the determination. The organic content is to be computed on the basis of the oven dry weight of the glass reinforced roving previous to the removal of the glass yarn insert.

ADOPTION OF TENTATIVES AS STANDARD

Tentative Methods of Testing and Tolerances for Glass Yarn (D 578 – 50 T), and

Tentative Method of Test for Vegetable Matter in Scoured Wool (D 1113 – 50 T):

The committee recommends that the

above two tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision.

Tentative Definition of Terms Relating to Textile Materials (D 123 – 51 T):

On the recommendation of Subcommittee B-2, Committee D-13 recommends that the definitions of the following terms in D 123 – 51 T be adopted as standard to replace those in Standard D 123 – 51: Elongation, Standard Condition, Warp, and Yarn.

It is also recommended that the definitions of the following terms in D 123 – 51 T be adopted as standard: Abrasion; Conformance; Consignment; Hygrometer; Moisture Equilibrium for Testing; Psychrometer; Rayon, *adj.*; Tare; Textiles, *n*; Weight, Gross; Weight, Net.

Tentative Method of Test for Yarn Number of Yarn from Fabrics (D 1059 – 49 T):

These tentative methods are recommended for adoption as standard with a minor revision in Section 6. Change the explanation for the symbol "L" used in the formula for calculating yarn number to read "L = yards of No. 1 yarn in 1 lb."

Tentative Method of Test for Colorfastness of Dyed Estron to Atmospheric Fumes (D 682 – 47 T):

It is recommended that this tentative method be adopted as standard with the following changes:

Title and Section 1.—Substitute "acetate" for "estron."

Section 2.—Change the first sentence to read as follows: "The apparatus shall consist of an enclosed metal chamber through which fumes from a lighted gas burner are passed in such a manner that uniform circulation can be obtained (Note 1)."

Note 5.—Change the last sentence of the last Paragraph to read as follows: "A sealed unit of control sample No. 1 comprising 20 yd. of ribbon $2\frac{1}{4}$ in. in width, along with a sample of the "standard of fading" may be obtained for $2.50 from Testfabrics Inc., 224 West 35th St., New York 1, N. Y."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Standard Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 44):

On the recommendation of Subcommittee A-3, the following proposed revision of the procedure for shrinkage in sponging is recommended for immediate adoption:

13. *Shrinkage in Sponging Test:* (*a*) *Scope.*—This test is designed to represent a standard method for reproducing on a laboratory level the results of commercially sponged fabrics.

(*b*) *Test Specimen.*—The specimen shall be fully conditioned at standard atmospheric conditions. It shall be laid out without tension on a flat, hard surface, care being taken that the cloth is smooth and free from wrinkles or creases. Three distances, each of 18 in. (or longer when the size of the specimen permits), shall be marked off on the specimen in both the warp and filling directions. The distances shall be parallel to the warp or filling threads, at least 6 in. apart, and at least 1 in. from all edges of the specimen. Satisfactory marks may be made with indelible ink and fine-pointed pen or by sewing fine threads into the cloth.

(*c*) *Wetting.*—The specimens shall be immersed in water to which has been added a nonionic wetting agent. The temperature shall be 75 to 85 F (24 to 29 C). The specimens shall be kept water-immersed for a period of 1 hr, or until thoroughly saturated.

(*d*) *Drying.*—The specimens shall be removed from the water. The excess water shall be removed from them in a centrifuge with as little distortion as possible. Wringing by hand or with squeeze rolls is not permissible as either may distort the cloth. The specimens shall then be spread out on a horizontal screen or similar perforated surface. The specimens shall be airdried at room temperature.

(*e*) *Pressing.*—The specimen shall be pressed with a flatbed press having steam pressure of 60 psi. The proper tension between heads shall be reached when a piece of paper may be removed from between the heads without tearing. The specimen shall be pressed for 15 sec. The head shall be raised and the specimen permitted to cool with vacuum. The specimen shall then be flapped and pressed for another 15 sec. After pressing, the head shall be raised, the fabric allowed to cool with vacuum, and then removed from the press.

(*f*) *Results.*—The pressed specimen shall be laid out without tension on a flat, hard surface, care being taken that the cloth is smooth and free from wrinkles or creases, allowed to recondition fully at standard atmospheric conditions, and the distances which were marked off shall be measured again. The shrinkage in the warp and in the filling directions of the cloth shall be calculated separately as the average obtained from the three marked distances. The shrinkage in sponging is the decrease in the distance measured and shall be expressed either as a percentage of the dimension before sponging or in inches per yard.

Recommended Practice for a Universal System of Yarn Numbering (D 861 – 50):

On the recommendation of Subcommittee B-2, it is proposed that this recommended practice be revised as appended hereto.[3]

Standard Methods of Testing and Tolerances for Single Jute Yarn (D 541 – 49):

On the recommendation of Subcommittee A-5, the following revisions are recommended for immediate adoption:

Section 11.—Change the first sentence to read as follows: "The weight of each conditioned skein of yarn shall be determined on balances sensitive to, and accurate within, 0.25 per cent of the indicated load."

Section 12.—Change Paragraph (*b*) to read as follows:

(*b*) All single strands shall be broken on a pendulum type of power-driven testing machine of which the tolerance of load indication, the working range, and the capacity shall conform to Standard Specifications for Textile Testing Machines (ASTM Designation: D 76), Sections 4 and 5.

The distance between centers of the spools or drums of the testing clamps shall be 10 ± 0.5 in. The speed of the pulling drum or capstan shall be 12 ± 0.5 in. without load. If the yarn breaks within 0.5 in. of the contact point on either drum, the result shall be discarded.

Section 15.—Change title to read as follows: "Extractable Matter by Direct Extraction." In line 2 of Paragraph (*a*) change "10 g" to read "20 g," and in the last line change "1 mg" to read "25 mg".

Change the first sentence of Paragraph (*b*) to read as follows: "Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, siphoning not less than 20 times with any of the specified solvents (Paragraph (*d*))."

Delete Notes 1 and 2 under Paragraph (*b*).

Add a new Paragraph (*d*) on solvents to read as follows:

(*d*) *Solvents.*—Any of the following solvents may be used: benzene, c.p.; chloroform, c.p.; diethyl ether, USP, or ethylene dichloride (boiling point 82.5 to 84 C, acidity not over 0.001 per cent).

Add a new note to Section 15 to read as follows:

NOTE.—While any of the permitted solvents will extract all the substances likely to occur, the following are preferred solvents for specified uses:

For	Solvent
Pine Tar	di-ethyl ether
Asphaltic materials (bitumens from petroleum)	chloroform
Creosote oil, anthracene oil, coal tar pitch (bitumens from coal tar)	benzene

Standard Methods of Testing and Tolerances for Jute Rove and Plied Yarn for Electrical and Packing Purposes (D 681 – 48):

On the recommendation of Subcommittee A-5, the following revisions are recommended for immediate adoption:

Section 11.—Change Paragraph (*b*) to read as follows:

(*b*) All single strands shall be broken on a pendulum type of power-driven testing machine of which the tolerance of load indication, the working range, and the capacity conform to the Standard Specifications for Textile Testing Machines (ASTM Designation: D 76), Sections 4 and 5.

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[3] The revised standard was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 7.

Section 12.—Change the first sentence to read: "The weight of each conditioned skein or length of yarn or rove shall be determined on balances sensitive to, and accurate within, 0.25 per cent of the indicated load."

Section 14.—Delete Notes 1 and 2 under Paragraph (*c*) and add a new Paragraph (*e*) to read the same as the new Paragraph (*d*) of Section 15, of Standard D 541 as given above.

Add as a new note to Section 14 the same note that is added above to Standard D 541, Section 15.

Change the first sentence of Paragraph (*c*) to read: "Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, siphoning not less than 20 times with any of the specified solvents (Paragraph (*d*))."

Standard Methods of Testing and Tolerances for Rope (Leaf and Bast Fibers) (D 738 - 46):

On the recommendation of Subcommittee A-5, the following revisions are recommended for immediate adoption:

Section 11.—Change title to read "Extractable Matter by Direct Extraction."

In the last line of Paragraph (*a*) change "1 mg" to read "25 mg."

Delete the two notes under Paragraph (*b*) and add a new Paragraph (*d*) to read the same as new Paragraph (*d*) under Section 15 of Standard D 541 as given above.

Change the first sentence of Paragraph (*b*) to read: "Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, siphoning not less than 20 times with any of the specified solvents (Paragraph (*d*))."

Standard Methods of Testing and Tolerances for Spun, Twisted, or Braided Products Made from Flax, Hemp, Ramie, or Mixtures Thereof (D 739 - 46):

On the recommendation of Subcommittee A-5, the following revisions are recommended for immediate adoption:

Section 15.—Delete the first sentence and substitute the following two sentences: "Each conditioned skein prepared in accordance with Section 14 shall be weighed on balances sensitive to, and accurate within, 0.25 per cent of the indicated load. The yardage, in the system agreed upon, shall be calculated to the nearest 0.25 per cent.

Section 16.—Change Paragraph (*b*) to read as follows:

(*b*) All single strands shall be broken on a pendulum type of power-driven testing machine of which the tolerance of load indication, the working range, and the capacity shall conform to Standard Specifications for Textile Testing Machines (ASTM Designation: D 76), Sections 4 and 5.

Section 23.—Change the title to read "Extractable Matter by Direct Extraction."

In last line of Paragraph (*a*) change "1 mg" to read "25 mg."

Delete the two notes under Paragraph (*b*).

Reletter Paragraph (*e*) as Paragraph (*c*) and add a new Paragraph (*d*) to read the same as the new Paragraph (*d*) under Section 15, of Standard D 541 as given above.

Add as a new Note 1 the same note that is added above as a new note to Section 15 of Standard D 541.

Change the first sentence of Paragraph (*b*) to read as follows: "Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, siphoning not less than 20 times with any of the specified solvents (Paragraph (*d*))."

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Standard Methods of Test for Hard Scoured Wool in Wool in the Grease (Laboratory Scale Operations) (D 584–50):

On the recommendation of Subcommittee A-3, it is proposed that these standard methods be revised and reverted to tentative, as appended hereto.[4]

ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends the adoption as standard of the tentative revisions[5] of the following five standards:

Standard Methods of Testing and Tolerances for Single Jute Yarn (D 541 – 49), revision of Section 10 (*b*).

Standard Specifications and Methods of Test for Asbestos Tape for Electrical Purposes (D 315 – 49), revision of Section 16.

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 49), revision of Sections 2 (*c*) and (*d*), 6, 8 (*a*) and (*b*).

Standard Methods of Testing Woven Asbestos Cloth (D 577 – 42), revision of Section 3.

Standard Methods of Testing Asbestos Tubular Sleeving (D 628 – 44), revision of Section 3.

WITHDRAWAL OF TERM "ESTRON"

The Tennessee Eastman Co. has requested from the American Society for Testing Materials the return of their full rights to the use of the word "estron" previously approved as a generic term for cellulose acetate products. This request is based on the fact that the Eastman Company's trade mark rights were transferred to the American Society for Testing Materials with the proviso that the term be adopted as standard and be used by the trade. As a matter of record, the word "estron" has not come into general use and, in consideration of the formal approval of the specific term "acetate" for fibers, filaments, yarns, and other products made from cellulose acetate by the Federal Trade Commission, and the fact that at present there is only one commercial cellulose ester fiber, the general use of the word "estron" is considered problematical. No other word is proposed to replace the term "estron" as a generic term for cellulose ester fibers and products at this time.

With the approval of Subcommittee A-2 on Man-Made Organic-Base Fibers and Their Products, and Subcommittee B-2 on Nomenclature and Definitions, Committee D-13 recommends the withdrawal of the term "estron" from all of its standards and definitions and the substitution of the term "acetate."

REAFFIRMATION OF STANDARDS

Committee D-13 recommends the reaffirmation of the following eight standards which have been published for six years or longer without revision:

Specifications and Methods of Test for Osnaburg Cement Sacks (D 205 – 39)
Specifications for Numbered Cotton Duck and Army Duck (D 230 – 44)
Tests and Tolerances for Knit Fabrics (D 231 – 46)
Tests and Tolerances for Woven Tapes (D 259 – 44)
Tests for Maximum Residual Shrinkage of Silk, Rayon, and Acetate Woven Fabrics (D 416 – 39)
Tests for Rayon and Acetate Staple (D 540 – 44)
Tests and Tolerances for Certain Fine Staple Cotton Gray Goods (D 679 – 44) and
Tests and Tolerances for Certain All-Cotton and Cotton and Rayon Fine Fancy Goods (D 680 – 44).

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[4] The revised methods were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 7.

[5] 1951 Supplement to Book of ASTM Standards, Part 5.

REPORT OF COMMITTEE D-14

ON

ADHESIVES*

Committee D-14 on Adhesives held one meeting during the year, a two-day meeting at Detroit on October 15 and 16, 1951.

At the present time the committee consists of 92 members, of whom 34 are classified as producers, 37 as consumers, and 21 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Gerald Reinsmith.
Vice-Chairman, G. F. Lipsey.
Secretary, L. M. Perry.
Membership Secretary, Alan Marra.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

On May 26, 1951, the Administrative Committee on Standards accepted the Tentative Recommended Practice for Determining the Effect of Moisture and Temperature on Adhesive Bonds (D 1151 - 51 T). The tentative recommended practice appears in the 1951 Supplement to Book of ASTM Standards, Part 4.

Subsequent to the 1951 Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Test for Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183 - 51 T), and

Test for Strength of Adhesives on Flexural Loading (D 1184 - 51 T).

These recommendations were accepted by the Standards Committee on July 10, 1951, and the new tentative methods appear in the 1951 Supplement to Book of ASTM Standards, Part 4.

Revisions of the Tentative Method of Test for Impact Strength of Adhesives (D 950 - 47 T) were accepted by the Standards Committee on February 15, 1952.

NEW TENTATIVE

Committee D-14 recommends that the following definitions of terms be accepted for publication as tentative, under the designation D 907:

Permanence.—The resistance of an adhesive bond to deteriorating influences.

Adhesive Dispersion.—A two phase system in which one phase is suspended in a liquid.

Syneresis.—The exudation of small amounts of liquid by some gels on standing.

Thixotropy.—A property of certain systems to thin upon isothermal agitation and to thicken upon subsequent rest.

Doctor-Bar or Blade.—A scraper mechanism which regulates the amount of adhesive on the spreader rolls or on the surface being coated.

Doctor-Roll.—A roller mechanism which is revolving at a different speed, or in an opposite direction, resulting in a wiping action for regulating the adhesives supplied to the spreader rolls.

Pick-up Roll.—A spreading device where the roll for picking up the adhesive runs in a reservoir of adhesive.

Warp (*noun*).—A significant variation from the original, true, or plane surface.

Yield Value.—The stress (either normal or shear) at which a marked increase in deformation occurs without an increase in load.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

Tentative Definitions of Terms Relating to Adhesives (D 907 - 49 T)[1] be approved for reference to letter ballot of the Society for adoption as standard without revision.

It is also recommended that the definition of the term "Consistency" (ASTM Designation: E 24-42),[1] be adopted for use in connection with adhesives ("That property of a body by virtue of which it tends to resist deformation").

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued in their present status without revision, pending further study:

Recommended Practice for:

Determining the Effect of Artificial (Carbon Arc Type) and Natural Light on the Permanence of Adhesives (**D 904 - 46 T**),

Method of Test for:

Impact Strength of Adhesives (**D 950 - 47 T**),
Strength Properties of Metal-To-Metal Adhesives in Shear by Tension Loading (**D 1002 - 49 T**), and
Consistency of Adhesives (**D 1084 - 50 T**).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Properties (C. B. Hemming, chairman).—Further progress on a new type tension test with a description of the testing machine used at the University of Michigan was reported by the Section on Tensile Strength. The Section on Shear Strength discussed modification of the overlap employed in Method D 1002 - 49 T and round robin results on a proposed method of test for rigid type plastic to plastic bonding.

Subcommittee II on Analytical Tests (L. Repsher, chairman).—A round robin study has been made to further confirm a proposed method of determining the nonvolatile content of urea resin adhesives. The method will be submitted to letter ballot of Subcommittee II.

Subcommittee III on Permanence (R. F. Blomquist, chairman).—The Section on the Effect of Moisture and Temperature has proposed revision of D 1183 - 51 T and this will be submitted to letter ballot of the subcommittee. Work at the Bureau of Standards on resin-bonded phenolic plastic material using a modification of D 1183 - 51 T has been reviewed. The Section on Biological Factors is preparing further methods for letter ballot of the committee. There is being prepared by the Section on Correlation of Short and Long Term Tests a questionnaire to determine various uses which the ASTM test sites may have in committee work.

Subcommittee IV on Working Properties (D. L. Swayze, chairman).—Two new methods are being further revised by the Section on Consistency. Preliminary round robin proving tests of a proposed "Tackmeter" have been made by the Section on Tack and Blocking. The Section on Storage and Working Life has submitted to the subcommittee a method on storage life and one on working life.

Subcommittee V on Specifications (F. H. Bair, chairman).—The Section on Adhesives for Acoustical Materials, by discussion and round robin tests, is preparing a draft of proposed specifications. The Section on Packaging Adhesives is determining if there is sufficient interest in Committee D-14 to warrant a program of work in this field. A new Section on Sampling and Inspection has been approved.

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[1] 1949 Book of ASTM Standards, Part 4.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee VI on Nomenclature (F. Moser, chairman).—Definitions of nine terms are being submitted to the Society with this report. Tentative Definitions of Terms D 907 - 49 T is being recommended by letter ballot of Committee D-14 for adoption as standard. Definitions of other terms are under consideration by the subcommittee.

Subcommittee VII on Research (R. C. Platow, chairman).—Current research problems have been reviewed, including a description of work at the National Bureau of Standards with high-frequency waves passed through liquid resin solutions. A new test for developing the rate of cure on thermosetting wood glues has been discussed. A conference, possibly at the fall, 1952, meeting of the committee, on non-destructive testing of adhesive bonds is proposed.

Subcommittee VIII on Electrical Properties (H. A. Perry, chairman).—Work is continuing on a proposed Tentative Method for Testing Adhesives for Electrical Insulation and it is proposed to expand the scope of this method.

A Symposium on Testing Adhesives for Durability and Permanence[3] is being held during this Annual Meeting.

This report has been submitted to letter ballot vote of the committee, which consists of 92 voting members; 56 members have returned their ballots, of whom 54 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

FRANK W. REINHART,
Chairman.

L. M. PERRY,
Secretary.

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[3] Issued as ASTM *STP No. 138.*

REPORT OF COMMITTEE D-15

ON

ENGINE ANTIFREEZES*

Committee D-15 on Engine Antifreezes held two meetings during the year: the first in Atlantic City, N. J. on October 26, 1951, and the second in Washington, D. C. on April 18, 1952. The Advisory Committee and subcommittees have held meetings concurrently.

There have been five resignations and six additions to the list of committee members during the year. At present the committee is composed of 41 active voting members, of whom 20 are classified as producers, 9 as consumers, and 12 as general interest members.

The following change in subcommittee chairmanship occurred during the year: P. I. Emch vice T. E. Bieterman as chairman of Subcommittee V on Effects of Antifreeze on Rubber Hose. E. F. Miller is the liaison member of this subcommittee with Subsection III-B on Coolant System Hose of the SAE-ASTM Technical Committee on Automotive Rubber of Committee D-11.

At its last meeting the Advisory Committee activated a new Subcommittee VIII whose responsibilities will be coordination and editorial. R. E. Mallonee is its chairman.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. R. Wolf.

Vice-Chairman, R. E. Mallonee.

Secretary, C. F. Graham.

Advisory Committee: J. M. Clark, Gus Kaufman, J. D. Klinger, R. E. Vogel, and L. W. Vollmer.

REVISION OF TENTATIVES

Tentative Method for Sampling and Preparing Aqueous Solutions of Engine Antifreeze (**D 1176 – 51 T**).[1]—The committee recommends the following revision of this method:

Title.—Add the words "for testing purposes," so that the title will read "Method for Sampling and Preparing Aqueous Solutions of Engine Antifreeze for Testing Purposes."

Section 1.—Revise this section on "Scope" to read as follows:

> 1. (*a*) This procedure is intended to establish a standard method of:
>
> (*1*) Obtaining a representative sample of predominately liquid commercial antifreeze from the original container,
>
> (*2*) Outlining a procedure for the separation of the water-soluble phase where required, and
>
> (*3*) Prescribing a method for the preparation of aqueous solutions.
>
> (*b*) The primary purpose is to aid in obtaining reproducible results in laboratory test methods.

Tentative Method of Test for Freezing Point of Aqueous Engine Antifreeze Solutions (**D 1177 – 51 T**).[1]—The committee recommends the following revision of this method:

Title.—Change the word "solutions" to the singular form so that the title will read "Method of Test for Freezing Point of Aqueous Engine Antifreeze Solution."

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1951 Supplement to Book of ASTM Standards, Part 5.

Section 1.—Revise this section on "Scope" to read as follows:

1. This method of test is intended for determining the freezing points of an aqueous engine antifreeze solution in the laboratory.

Section 6.—Transfer Note 1 from Section 6 to the end of Section 1.

Section 7.—Revise this section on "Report" to read as follows by the addition of the italicized words:

7. Plot the observed temperature against time on rectangular coordinate paper. Where the curve shows a definite flat or plateau during freezing, the freezing point is taken as the intersection of projections of the cooling curve and *the flat or horizontal plateau portion of the* freezing curve (see Fig. 2(*a*). If the solution undercools, the freezing point is the maximum temperature reached immediately after undercooling (see Fig. 2(*b*)).

NOTE.—The amount of undercooling should be held to a minimum. If the undercooling exceeds 2 F, the test should be rejected.

Figure 2.—In Fig. 2(*a*) extend the horizontal dotted line through and beyond the flat or plateau. The words "Freezing Point" should appear below this line and the arrow point up to the intersection of this horizontal line and the dotted extension of the cooling curve.

In Fig. 2(*b*) the words "Freezing Point" should appear above the maximum in the curve and the arrow point down to the maximum.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following six tentatives be continued as tentative without revision:

Tentative Specifications for:

Hydrometer-Thermometer Field Tester for Engine Antifreezes (D 1124 – 50 T),

Tentative Methods of Test for:

Ash Content of Concentrated Engine Antifreezes (D 1119 – 50 T),

Boiling Point of Engine Antifreezes (D 1120 - 51 T),

Reserve Alkalinity of Concentrated Engine Antifreezes (D 1121 – 50 T),

Specific Gravity of Concentrated Engine Antifreezes by the Hydrometer (D 1122 – 50 T), and

Water in Concentrated Engine Antifreezes by the Iodine Reagent Method (D 1123 – 50 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Freezing Point Determination (R. E. Mallonee, chairman) has been responsible for the changes proposed in the Tentative Method of Test for Freezing Point of Aqueous Engine Antifreeze Solution (D 1177 – 51 T).

Subcommittee II on Antifreeze Field Testers (J. D. Klinger, chairman) has kept itself informed as to various mechanisms which have from time to time been proposed for field testing of antifreezes to determine freezing protection. The subcommittee is in agreement that it will be officially interested in setting standards only when a mechanism is in large scale production for widespread use.

Subcommittee III on Physical Properties (R. E. Vogel, chairman) has been studying the desirability of a technique for the measurement of viscosity of engine antifreezes at low temperatures. Information was received from Committee D-2 on low-temperature viscosity determination. The D-2 Proposed Method of Test for kinematic viscosity[3] published as information in 1951 is being considered as a suitable method for this purpose when an accurate temperature measuring device is employed. The report prepared by E. F. Harford and J. J. Moran on "Some Observations on the Use of Hydrometers for Determining Specific Gravity of Antifreezes based on Collaborative Work in ASTM Committee D-15" has been submitted to Subcommittee 18 on Hydrometers, of Committee E-1 on Methods of Testing, to assist in its preparation of a test method for verifying hydrometers and in the preparation of a recommended practice for the use of hydrometers.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 320 (1951); also compilation of "ASTM Standards on Petroleum Products and Lubricants," September, 1951, p. 718.

Subcommittee IV on Chemical Properties (E. G. Travis, chairman) in its study of the pH determination of new unused antifreezes has prepared the first draft of the pH determination method involving known aqueous dilutions of new unused antifreeze. Cooperative tests are being started in order to expand the ash determination method to permit the determination of solids upon evaporation prior to the ashing step.

Subcommittee V on Effects of Antifreeze on Rubber Hose (T. E. Bieterman, chairman) has completed two series of rubber immersion cooperative tests. The first series of test involved a side by side run of the SAE-ASTM immersion test procedure along with the individual collaborators' own type of rubber test using three standard types of rubber in a standard coolant. The second series of test involved a single test procedure which had been agreed upon after the first series with standard rubber compounds and standard coolants, using both the high-boiling and low-boiling types of antifreeze. Results of this second test series are being correlated. While it is understood that this type of beaker immersion test may not necessarily represent actual cooling system services, its relationship to automobile field test results and methods for determining its validity are under consideration.

Subcommittee VI on Simulated and Actual Service Testing (E. F. Harford, chairman).—The Study Group on Simulated and Actual Service Testing (C. H. Sweatt, chairman) has agreed on several modifications of the glassware apparatus and technique for the corrosion test based on the first cooperative shakedown test series. The study group is starting a limited number of additional shakedown tests with the revised apparatus and technique before making recommendations to Subcommittee VI. Subcommittee VI and Committee D-15 have agreed to make the corrosion test data available to the new SAE Committee on Cooling System Corrosion with the understanding as to the limitations of the data because the tests are still in the process of development.

The Study Group on Preparation of Antifreeze and Cooling System Recommendations (Gus Kaufman, chairman) has completed a most excellent general interest article on the "Selection and Use of Engine Antifreeze"[4] which should be of practical interest to the lay public.

Subcommittee VII on Specifications (J. M. Clark, chairman) has prepared a general outline form for an antifreeze performance specification using the existing test methods and those being developed in the other subcommittees, but this is still dependent upon the projects under investigation by the other subcommittees to provide the necessary information for the specification limits.

The Study Group on Sampling (R. E. Mallonee, chairman) is responsible for the changes being proposed in the Tentative Method for Sampling and Preparing Aqueous Solutions of Engine Antifreezes (D 1176 - 51 T).

The Study Group on Classification of Antifreeze (O. C. Cessna, chairman) after study of the classification problem, recommended that the classification activity be made a part of the responsibility of Subcommittee VII on Specifications because of its close relationship to specifications. The request was approved by Committee D-15.

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[4] Issued as separate publication *ASTM STP No. 120.*

This report has been submitted to letter ballot to the committee, which consists of 41 voting members; 39 members have returned their ballots, of whom 34 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. R. WOLF,
Chairman.

C. F. GRAHAM,
Secretary.

REPORT OF COMMITTEE D-16

ON

INDUSTRIAL AROMATIC HYDROCARBONS AND RELATED MATERIALS*

Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials, the Advisory Committee, and several of its subcommittees held meetings in Cleveland, Ohio, during ASTM Committee Week on March 5 and 6, 1952. Additional meetings of the committee will also be held during the 1952 Annual Meeting.

At the Spring Meeting a resolution of differences between Committee D-16 and Committee D-1 on Paint, Varnish, Lacquer, and Related Products appeared to have been obtained on the harmonizing and combination of the Specifications for Industrial 90 Benzene (D 837 and D 361), Industrial Grade Toluene (D 842 and D 362), and Industrial Grade Xylene (D 844 and D 364). Drafts of proposed consolidated specifications prepared at the Spring Meeting were subsequently submitted to letter ballot vote of both committees. Objections received in connection with negative votes on the proposed specifications warranted reconsideration of the specifications, and they were accordingly withheld for further study. It is expected that the differences will be resolved during the year.

Committee D-16 is now actively functioning under its enlarged scope which reads as follows:

Scope.—Nomenclature, specifications, and methods of test of those aromatic and heterocyclic chemicals, generically classed as coal chemicals, whether derived from coal, petroleum, or any other source by synthesis or physical separation, and used industrially, either alone or as mixtures, as intermediates or solvents.

In addition to the Advisory Committee, five subcommittees have been organized as indicated later in this report. Some additions have been made to the personnel of the committee, and consideration is being given to further enlarging the membership. The subcommittees are beginning to function actively under the new scope, and there has been an increasing number of applications for membership on these subcommittees.

The election of officers resulted in the selection of the following for the ensuing term of two years:

D. F. Gould, chairman.
E. C. Medcalf, vice-chairman.
F. J. Powell, secretary.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee A on Monocyclic Aromatics (S. S. Kurtz, Jr., chairman) has under cooperative study the bromine index and acid wash test on benzene samples containing cyclo-hexene and thiophene, with particular attention being given to the effect of thiophene. These studies are being carried out in connection with the ASTM Methods of Test for Bromine Number of Petroleum Distillates (Color-Indicator Method) (D 1158 – 51 T), Bromine Number of Petroleum

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Distillates (Electrometric Method) (D 1159 - 51 T), Acid Wash Color of Benzene, Toluene, Xylenes, Refined Solvent Naphthas, and Similar Industrial Aromatic Hydrocarbons (D 848 - 47), and Thiophene in Benzene (D 931 - 50).

Subcommittee B on Polycyclic Aromatics (Malcolm Mitchell, chairman) has undertaken as its initial project a study of naphthalene test methods.

Subcommittee C on Phenolic Compounds (V. S. Morello, chairman) is studying test methods for phenol.

Subcommittee D on Nitrogen Heterocyclics (E. C. Medcalf, chairman) has selected for its initial projects methods of test for pyridine and quinoline.

Subcommittee E on Nomenclature (K. H. Ferber, chairman) is studying definitions and nomenclature relating to xylenols.

Respectfully submitted on behalf of the committee,

D. F. GOULD,
Chairman.

B. F. HERR,
Secretary.

REPORT OF COMMITTEE D-17

ON

NAVAL STORES*

Committee D-17 on Naval Stores held one meeting during the past year, at the Annual Meeting of the Society on June 21, 1951, in Atlantic City, N. J. At the time of the Spring Meeting in Cleveland, Ohio, in March, 1952, the progress on the agenda of most of the subcommittees did not seem to warrant calling a meeting of the general committee. Following previous practice, the activities of all subcommittees were reported and discussed at length in the main committee meeting on June 21, thus making unnecessary the holding of separate subcommittee meetings. In this way, further revisions were worked out in two tentatives (Methods D 464 and D 465) which were adopted as standard in their revised form in 1951. The 1951 report also contained a recommendation regarding the adoption as standard of another tentative (Method D 1065). This recommendation was withdrawn in order to permit further study of a part of the method, using a new procedure that had been developed. These actions as reported to the Society at the 1951 Annual Meeting, were confirmed by letter ballot of the committee.

In accordance with the action of the Advisory Committee, a new Subcommittee on Specifications was organized and has been active in the preparation of specifications for rosin, dipentene, and pine oil. The limitations on ASTM specifications for such products, which in many instances are manufactured in several grades to meet special needs of the users, have been kept in mind, as it is not the desire of the committee to recommend any action regarding specifications which would affect any close supplier-purchaser relationship in the furnishing of special grades of material.

At the suggestion of several members of the committee, and in keeping with a recommendation made in the 1951 Report of the committee, it is proposed to include in the Standard Methods of Sampling and Grading Rosin (D 509 - 45) a description of the colors of the U. S. Official Rosin Standards for the various grades of rosin, as prepared and made available by the U. S. Department of Agriculture, in terms of spectral transmission factors and the fundamental colorimetric specifications, based on the 1931 ICI coordinate system. These data were originally published in a scientific journal,[1] some time after the official adoption in 1936 of the modified standards for rosin, made of glass, but it is felt that the data might be generally useful if also made available in an ASTM publication in connection with Standard Methods D 509. The data are given in the accompanying Tables I and II.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, V. E. Grotlisch.
Vice-Chairman, J. L. Boyer.
Secretary, W. A. Kirklin.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Journal, Optical Society of America, Vol. 30, No. 4, pp. 152-158 April, 1940.

PROPOSED SPECIFICATIONS TO BE PUBLISHED AS INFORMATION

Committee D-17 recommends that the following three proposed specifications be published as information, as appended hereto.[2]

Proposed Specifications for:

Dipentene,
Pine Oil, and
Rosin

TABLE I.—SPECTRAL TRANSMISSION FACTORS FOR U S ROSIN STANDARDS (MASTER SET NO. 200).

Wave Length, λ, mμ	GRADE											
	X	WW	WG	N	M	K	I	H	G	F	E	D
400	0.005	0.001										
410	0.006	0.0022	0.0008									
420	0.0092	0.0037	0.0015									
430	0.0152	0.0064	0.0026	0.0008								
440	0.0311	0.0139	0.0059	0.0020	0.0005							
450	0.0595	0.0284	0.0131	0.0048	0.0013	0.0002						
460	0.106	0.0549	0.0280	0.0114	0.0035	0.0007						
470	0.166	0.0926	0.0512	0.0232	0.0083	0.0020	0.0003					
480	0.234	0.143	0.0863	0.0437	0.0181	0.0053	0.0009					
490	0.305	0.199	0.1305	0.0734	0.0346	0.0119	0.0027	0.0003				
500	0.373	0.260	0.181	0.1114	0.0589	0.0239	0.0074	0.0011	0.0001			
510	0.440	0.324	0.237	0.1587	0.0932	0.0434	0.0159	0.0033	0.0006			
520	0.502	0.387	0.299	0.213	0.1372	0.0730	0.0316	0.0089	0.0020			
530	0.556	0.450	0.363	0.273	0.190	0.1130	0.0566	0.0200	0.0060			
540	0.604	0.506	0.422	0.333	0.246	0.158	0.0896	0.0373	0.0136			
550	0.643	0.555	0.477	0.394	0.302	0.210	0.1320	0.0635	0.0275	0.0004		
560	0.673	0.595	0.526	0.447	0.358	0.264	0.178	0.0972	0.0482	0.0099	0.00006	
570	0.698	0.628	0.567	0.495	0.411	0.316	0.227	0.1357	0.0760	0.0417	0.0034	
580	0.713	0.651	0.597	0.533	0.454	0.363	0.272	0.174	0.1070	0.0655	0.0149	0.00015
590	0.724	0.668	0.620	0.562	0.489	0.400	0.312	0.210	0.1414	0.0804	0.0260	0.0015
600	0.730	0.678	0.635	0.582	0.514	0.430	0.345	0.242	0.174	0.1015	0.0354	0.0046
610	0.729	0.683	0.642	0.594	0.530	0.449	0.368	0.265	0.200	0.1190	0.0450	0.0078
620	0.727	0.684	0.645	0.600	0.540	0.462	0.384	0.281	0.219	0.1358	0.0549	0.0109
630	0.724	0.682	0.646	0.603	0.545	0.469	0.393	0.292	0.233	0.152	0.0652	0.0142
640	0.722	0.682	0.647	0.606	0.550	0.475	0.401	0.302	0.244	0.167	0.0750	0.0177
650	0.723	0.683	0.650	0.610	0.555	0.482	0.408	0.309	0.253	0.181	0.0854	0.0216
660	0.724	0.684	0.652	0.612	0.558	0.485	0.413	0.314	0.259	0.197	0.0969	0.0266
670	0.729	0.688	0.658	0.618	0.564	0.494	0.419	0.322	0.266	0.214	0.1099	0.0322
680	0.738	0.698	0.667	0.628	0.573	0.504	0.428	0.331	0.270	0.234	0.1236	0.0389
690	0.738	0.699	0.668	0.629	0.574	0.505	0.429	0.331	0.270	0.253	0.139	0.0472
700	0.741	0.704	0.673	0.633	0.577	0.509	0.431	0.334	0.269	0.273	0.155	0.0568
710	0.749	0.710	0.678	0.639	0.584	0.515	0.435	0.336	0.267	0.294	0.173	0.0683
720	0.756	0.717	0.685	0.644	0.588	0.518	0.436	0.336	0.264	0.316	0.191	0.0821
730	0.763	0.723	0.691	0.648	0.590	0.519	0.435	0.335	0.258	0.340	0.212	0.0990
740	0.769	0.727	0.694	0.650	0.591	0.519	0.433	0.330	0.250	0.365	0.235	0.117
750	0.773	0.731	0.696	0.651	0.590	0.516	0.428	0.324	0.240	0.390	0.258	0.139
760	0.778	0.734	0.698	0.651	0.587	0.512	0.421	0.317	0.229	0.416	0.283	0.162

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Definition of Terms Relating to Naval Stores and Related Products (D 804 – 51 T)[3] be adopted as standard and incorporated in the present Standard D 804 with the addition of a new definition as follows:

Sulfate Pine Oil.—A high boiling fraction obtained in the refining and fractional distillation of the condensed vapors released during the digestion of wood by the sulfate process.

Also revise the definition for Tall Oil Rosin by the addition of the italicized words, to read as follows:

Tall Oil Rosin.—Rosin remaining after the removal of *substantially all* of the fatty acids from tall oil by fractional distillation or other suitable means. Such rosin shall have the characteristic form, appearance, and other physical and chemical properties normal for other kinds of rosin. *The fatty acid content shall not exceed 5 per cent.*

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[2] See pp. 486 to 489.

[3] 1951 Supplement to Book of ASTM Standards, Part 4.

TABLE II.—COLORIMETRIC SPECIFICATIONS FOR U S ROSIN STANDARDS (MASTER SET NO. 200).

Grade	x^a	y^a	T^a	λ^a	p^a
X	0.4339	0.4663	0.609	575.0	0.755
WW	0.4579	0.4732	0.531	576.8	0.851
WG	0.4785	0.4741	0.466	578.5	0.905
N	0.5001	0.4704	0.396	580.5	0.944
M	0.5212	0.4619	0.322	582.8	0.969
K	0.5430	0.4483	0.245	585.5	0.985
I	0.5649	0.4310	0.178	588.7	0.993
H	0.5879	0.4102	0.1114	592.4	0.997
G	0.6116	0.3874	0.0723	596.8	0.999
F	0.6364	0.3632	0.0398	602.1	1.000
E	0.6640	0.3358	0.0131	609.4	1.000
D	0.6943	0.3057	0.0021	621.4	1.000

[a] x and y, are ICI trilinear coordinates; T is the luminous transmission factor; λ is the dominant wave length, in mμ; p is the colorimetric purity.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions in two standards and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Methods of Sampling and Grading Rosin (**D 509 – 45**):[4]

Section 2.—Delete the third and fourth sentences of Paragraph (*e*) beginning with "If 'type' samples," and substitute the following:

These standards (other than FF) consist of combinations of Corning and Jena colored glass plates, from selected melts, ground and polished to specified thicknesses. The spectral transmission data for the various assembled standards comprising the Master set No. 200, for light of different wave lengths, are given in Table I. The colorimetric specifications of the standards, based on the 1931 ICI Coordinate System, for a standard observer using standard illuminant *C*, are given in Table II.

Add a new Paragraph (*f*) to read as follows:

(*f*) Secondary standards or "types," made of selected rosin or suitable transparent thermosetting plastic material, in the form of $\frac{7}{8}$-in. cubes, are available. It is possible that other types of material (or solutions) might be used. Any such secondary standard shall be protected as much as possible from exposure to heat or direct sunlight, to avoid deformation or change of color, and kept wrapped and boxed in a cool, dark place when not in use. They shall be tested periodically for color, and replaced when they no longer match the standards.[4]

NOTE.—It is not possible to dissolve a specified quantity of rosin in a solvent and use such solution as a standard or for grading the rosin, because there is no constant relationship between the color of the original solid rosin and the color of the rosin after being put in solution. Consequently, the color of such solution is not a criterion of the color of the rosin itself.

Footnote 3.—Change to read as follows:

The U. S. Rosin Standards are issued only on security loan ($100 deposit) by the Naval Stores Division, Tobacco Branch, Production and Marketing Administration, U. S. Department of Agriculture, Washington, D. C., under Regulations for Enforcement of the Naval Stores Act.

Footnote 4.—Add a new footnote to read as follows:

The Department of Agriculture will examine and report on the suitability of any secondary standards for rosin, after suitable arrangements have been made with the Naval Stores Division. There is a fee for such service. Information on sources of supply of secondary standards may be obtained from the Naval Stores Division.

Standard Method of Test for Toluene Insoluble Matter in Rosin (**D 269 – 30**):[4]

Section 3.—Change the tense of the verbs "dry," "cool," and "weigh" to the past tense, to agree with the tense of the verb "washed."

Section 4.—Add a new section titled "Report," covering the computation and report of the results of the test, to read as follows: "4. Calculate and report the percentage of toluene insoluble solid matter in rosin to the second decimal place."

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[4] 1949 Book of ASTM Standards, Part 4.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (J. M. Schantz, chairman).—While no active work on the softening point test has been conducted by the subcommittee, several members have conferred with Subcommittee 9 of Committee E-1 and Subcommittee IV of Committee D-4, in which active study is being made of the softening point of tars and asphalts, using the Ring and Ball Softening Point Method (E 28 – 51 T). Considerable progress has been made toward reconciling differences in design of apparatus and test procedure between this method and Method D 36 – 26. A single ASTM softening point method applicable to both resinous materials like rosin and to asphaltic materials will probably result from these studies. Attention is being given in another committee to the preparation of the ring test samples, without preliminary melting, by compressing the resin in powdered form into the ring. This is necessary because many synthetic resins undergo decomposition when melted to prepare a ring test sample.

Subcommittee IV on Chemical Analysis of Rosin (R. Herrlinger, chairman).—Plans are under way for further study of several troublesome features of the present Tentative Method of Test for Unsaponifiable Matter in Rosin (D 1065–51 T). Until such further work is completed, recommendation cannot be made for adoption of the method as standard.

Subcommittee V on Tall Oil (A. Pollak, chairman).—Samples of six specially prepared mixtures of rosin acids (purified from tall oil) and fatty acids (from soybean oil) were sent out to 19 collaborative laboratories. These samples represented refined tall oils of lower rosin acid content than whole tall oils and had the following theoretical rosin acid contents: 0, 1.0, 3.0, 6.0, 10.0, and 14.8 per cent. The samples were analyzed for rosin acids by a new method developed in the laboratory of one of the committee members. The method, which is designed to supplant the Wolff method for rosin acids in tall oil, will be published in detail together with information regarding its development and technique in an early issue of the *Journal* of the American Oil Chemists' Society. The results obtained by the collaborators were in unusually good agreement and indicated that the method should prove satisfactory for low rosin acid tall oils. The deviation in the results on several samples reported by a number of the laboratories, and suggestions that further comparisons be made of this method with previously published methods (such as the McNicholl and the Linder-Persson methods) are being considered. From this study it is hoped to be able to present the best procedure for determining the rosin acids in highly refined tall oils, for eventual addition to the Standard Methods of Testing Tall Oil (D 803 – 51).

Work has been started on the study of methods for determining small amounts of rosin and rosin acids in finished products such as paint, varnish, and synthetic resins. This subcommittee is collaborating with a new task group in

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee IX on Varnish, of the Society's Committee D-1 on Paint. Six samples of material have been prepared and distributed for this work.

Subcommittee VII on Terpene Hydrocarbons and Pine Oils (R. E. Price, chairman).—Further consideration has been given to the question as to whether the ASTM distillation Method D 86 (using a 100-ml flask) or Method D 1078 (using a 200-ml flask) should be the standard method for running the distillation test on turpentine and related oils. On the basis of the results obtained in collaborative distillation tests by members of the subcommittee in 1948, it was concluded that the distillation data by the two methods were alike for such materials as turpentine, dipentene, and pine oil, within the limits of experimental error, and that the present reference to Method D 86 for distillation of such materials should remain in the standard methods of test applicable thereto; also that Method D 1078 should be permitted as an alternate method, with D 86 as the referee method in case of a dispute over distillation results on a sample. The subcommittee is considering the possibility of developing a method for determining peroxides in terpene hydrocarbon oils, and this question will be discussed at the June meeting of the committee.

Subcommittee VIII on Rosin Oil (V. E. Grotlisch, acting chairman).—The tentative methods for testing rosin oil have been circulated among producers and consumers of this type of material and no adverse comment or criticism has been submitted. It is believed to be advisable, however, to retain the method as tentative for one more year.

Subcommittee IX on Definitions (J. L. Boyer, chairman).—The activities of this subcommittee have been incorporated in the recommendation for adoption as standard of the present tentative definitions as previously shown in this report.

Subcommittee X on Specifications (S. R. Snider, chairman).—This subcommittee has actively considered the problem of preparing ASTM specifications for naval stores products, other than spirits of turpentine, for which latter material standard specifications have long been in existence. The results of this activity are shown in the preliminary Proposed Specifications for Dipentene, Pine oil, and Rosin, which are appended to this report. Comment or criticism of these proposed specifications is invited.

This report has been submitted to letter ballot of the committee, which consists of 40 voting members; 30 members returned their ballots, of whom 29 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-17 presented to the Society through the Administrative Committee on Standards proposed Tentative Methods of Test for Rosin Acids in Fatty Acids. The methods were accepted by the Standards Committee on September 23, 1952, and they appear in the 1952 Book of ASTM Standards, Part 4, bearing the designation D 1240 - 52 T.

APPENDIX I

PROPOSED SPECIFICATIONS FOR DIPENTENE[1], [2]

These specifications are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.

Scope

1. These specifications cover a single grade of commercial dipentene, as defined in the Standard Definitions of Terms Relating to Naval Stores and Related Products (ASTM Designation: D 804),[3] containing only limited quantities of other terpene hydrocarbons. It is obtained by fractional distillation from the higher boiling portions of several kinds of turpentine, but the purchaser shall have the right to specify the kind or source of the dipentene to be delivered under a contract based on these specifications.

Appearance

2. Dipentene shall be bright and clear, and free from sediment or suspended matter. The presence of separated water shall be cause for rejection, at the option of the purchaser.

Color

3. The color of dipentene shall be that known in the trade as "prime white," unless otherwise specified, and shall be not darker than No. 16 Saybolt, or than that of an aqueous solution containing 0.012 g of pure potassium dichromate in 1 liter of distilled water.

Properties

4. Dipentene shall conform to the requirements given in Table I.

Moisture

5. As an alternative qualitative test for dissolved water, mix 1 part by volume of dipentene with 19 parts by volume of gasoline having a specific gravity of 60° API. After shaking vigorously, the mixture shall remain clear and free from turbidity on standing for 5 min.

TABLE I.—REQUIREMENTS FOR DIPENTENE.

	Min	Max	ASTM Designation[a]
Specific gravity, 15.5/15.5 C.	0.845	0.860	D 801
Refractive index at 20 C....	1.472	1.477	D 801
Polymerization residue, per cent..................	....	3.0	D 233
Flash point..................	110 F	....	D 56
Aniline point................	....	15 C	D 801
Distillation: initial boiling point..................	168 C	....	D 801
Below 173 C, per cent.....	....	5	D 86
Below 188 C, per cent.....	95	....	
Dissolved water, per cent by weight..................	....	0.02	D 890

[a] See Section 7.

Copper Corrosion

6. Dipentene shall not blacken a strip of brightly polished sheet copper after the copper has been immersed in the boiling liquid for 30 min.

Methods of Testing

7. Dipentene shall be tested, and the properties enumerated in these specifications shall be determined, in accordance with the Standard Methods of Sampling and Testing Dipentene (ASTM Designation: D 801).[3] For convenience of reference, the ASTM designations of those methods that are referred to in the methods for dipentene are also shown in Table I.

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[1] These proposed specifications are under the jurisdiction of ASTM Committee D-17 on Naval Stores.

[2] Published as information, June, 1952.

[3] 1951 Supplement to 1949 Book of ASTM Standards, Part 4.

APPENDIX II

PROPOSED SPECIFICATIONS FOR PINE OIL[1, 2]

These specifications are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.

Scope

1. These specifications cover two kinds of pine oil, namely, steam-distilled pine oil and destructively distilled pine oil, as these products are defined in the Standard Definitions of Terms Relating to Naval Stores and Related Products (ASTM Designation: D 804).[3] Separate quality requirements are given for two grades of steam-distilled pine oil, to conform with what has been described in the trade as "premium grade" pine oil and as "standard grade" pine oil. The purchaser must determine and specify the grade and kind of pine oil desired.

TABLE I.—REQUIREMENTS FOR PINE OIL.

	Steam-Distilled Pine Oil				Destructively Distilled Pine Oil		ASTM Designation[a]
	ASTM Grade I		ASTM Grade II		Min	Max	
	Min	Max	Min	Max			
Specific gravity, 15.5/15.5 C	0.940	0.947	0.920	0.940	0.900	0.940	D 802
Refractive index, 20 C	1.481	1.492	1.479	1.481	1.479	1.490	D 802
Water, per cent by weight	....	1.0	....	1.0	....	1.0	D 890
Polymerization residue, per cent	....	2.5	....	2.5	....	5.0	D 233
Refractive index of residue at 20 C	1.500	....	1.500	....	1.500	....	D 802
Terpene alcohols, total, per cent	75	95	65	75	[b]	[b]	D 802
Acid number, total	....	2.0	....	2.0	....	10.0	D 233
Distillation: recovered below 185 C, per cent	....	....	....	5.0	....	5.0	D 86
Below 200 C, per cent	....	5.0	....	10.0	....	....	
Below 225 C, per cent	95.0	....	90.0	....	90.0	....	

[a] See Section 6.

[b] The maximum-minimum alcohol content of destructively distilled pine oil has not been established with finality. This property has rarely been considered in the evaluation of this type of pine oil.

Appearance

2. The pine oil shall be bright and clear in appearance, and shall be free from suspended matter and separated water.

Color

3. The color of pine oil shall be not darker than a pale straw yellow. When viewed through a 1-in. cell, the color shall be not darker than a No. 6.0 Lovibond yellow colorimeter glass. When tested by means of a Saybolt colorimeter the color shall be not darker than No. 19 Saybolt.

Odor

4. Pine oil shall have a characteristic piney (aromatic) odor; it shall be free

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[1] These specifications are under the jurisdiction of the ASTM Committee D-17 on Naval Stores.

[2] Published as information, June, 1952.

[3] 1949 Book of ASTM Standards, Part 4.

from pungent, strongly empyreumatic, or putrid odors that irritate the nasal membranes. Well refined, destructively distilled pine oil usually has a slightly empyreumatic odor, characteristic of this type of oil.

Test Properties

5. Pine oil shall conform to the requirements given in Table I.

Methods of Testing

6. The material shall be tested, and the properties enumerated in these specifications shall be determined, in accordance with the Standard Methods of Sampling and Testing Pine Oil (ASTM Designation: D 802).[3] For convenience of reference, the ASTM designations of those methods that are referred to in the methods for pine oil are also shown in Table I.

APPENDIX III

PROPOSED SPECIFICATIONS FOR ROSIN[1,2]

These specifications are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.

Scope

1. These specifications cover the grades of gum rosin, wood rosin, and tall oil rosin frequently referred to as medium and pale grades, as well as the normal grade of wood rosin known as grade FF. They do not cover specially made, specially treated, or modified rosins as defined in the Standard Definitions of Terms Relating to Naval Stores and Related Products (ASTM Designation: D 804).[3]

Properties

2. Rosin shall conform to the requirements given in Table I.

Sampling and Testing

3. The rosin shall be sampled, and the properties enumerated in these specifications shall be determined, in accordance with the following methods of the American Society for Testing Materials:

(*a*) *Sampling and Grading.*—Standard Methods of Sampling and Grading Rosin (ASTM Designation: D 509).[3]

(*b*) *Softening Point.* — Tentative Method of Test for Softening Point by Ring and Ball Apparatus (ASTM Designation: E 28).[3]

(*c*) *Acid Number.*—Standard Methods of Test for Acid Number of Rosin (ASTM Designation: D 465).[3]

(*d*) *Saponification Number.*—Standard Methods of Test for Saponification Number of Rosin (ASTM Designation: D 464).[3]

(*e*) *Unsaponifiable Matter.*—Tentative Method of Test for Unsaponifiable Matter in Rosin (ASTM Designation: D 1065).[3]

(*f*) *Toluene Insoluble Matter.*—Standard Method of Test for Toluene Insoluble Solid Matter in Rosin (ASTM Designation: D 269).[3]

(*g*) *Specific Gravity.*—Standard Method of Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements, and Soft Tar Pitches (ASTM Designation: D 70);[4] and Standard Method of Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (ASTM Designation: D 71).[4]

(*h*) *Ash.*—Standard Method of Test for Ash in Rosin (ASTM Designation: D 1063).[3]

(*i*) *Volatile Oil.*—Standard Method of Test for Volatile Oil in Rosin (ASTM Designation: D 889).[3]

(*j*) *Fatty Acids.*—Standard Methods of Testing Tall Oil (ASTM Designation: D 803).[3]

NOTE.—The fatty acid content of tall oil rosin is calculated from the difference between the total acid number and the rosin acid number, as follows:

Fatty acids, per cent

$$= \frac{(A - R) \times 0.282}{56.1} \times 100$$

where:

A = total acid number, and
R = rosin acid number.

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[1] These proposed specifications are under the jurisdiction of ASTM Committee D-17 on Naval Stores.

[2] Published as information, June, 1952.

[3] 1951 Supplement to 1949 Book of ASTM Standards, Part 4.

[4] 1952 Book of ASTM Standards, Part 3.

TABLE I.—REQUIREMENTS FOR ROSIN.

	Gum Rosin, Refined Wood Rosin		Dark Wood Rosin		Tall Oil Rosin		ASTM Designation[a]
	Min	Max	Min	Max	Min	Max	
Color grade	H	X	FF[b]	....	M	X	D 509
Softening point (ring and ball)	70 C 158 F	85 C 185 F	67 C 152 F	81 C 177 F	70 C 158 F	88 C 190 F	E 28
Acid number	158	172	150	158	160	170	D 465
Saponification number	166	184	162	171	168	178	D 464
Unsaponifiable matter, per cent	....	10.7	....	14.0	....	7.5	D 1065
Toluene insoluble matter, per cent	....	0.05	....	0.05	....	0.05	D 269
Specific gravity at 77 F	1.06	1.09	1.06	1.09	1.06	1.09	D 70 D 71
Ash, per cent	....	0.1	....	0.05	....	0.05	D 1063
Volatile oil, per cent	....	1.0	....	1.0	....	0.05	D 889
Fatty acids, per cent[c]	....	....	....	....	....	5.0	D 803

[a] See Section 3.

[b] Only one grade of dark wood rosin is ordinarily made, for which the grade FF was promulgated under the Federal Naval Stores Act. Grade FF rosin has a brilliant dark red color. The color standard for this grade consists of Lovibond color glasses, cemented together, of the following values: 20 Yellow, 165 Red, 2.0 Blue.

[c] See Note, Section 3.

REPORT OF COMMITTEE D-18
ON
SOILS FOR ENGINEERING PURPOSES*

Committee D-18 on Soils for Engineering Purposes held two meetings during the year: at Atlantic City, N. J., on June 20, 1951, and in Cleveland, Ohio, during Spring Committee Week on March 5, 1952. A separate Executive Subcommittee meeting was held on January 13, 1952, in Washington, D. C.

Two symposiums were held at the 1951 Annual Meeting. The first, entitled Consolidation Testing of Soils, occupied one session and consisted of eight papers. The second symposium, on Surface and Subsurface Reconnaissance, occupied two sessions and included fifteen papers. The latter symposium was in the form of a panel discussion which was very well received. All the papers and discussions are being published by the Society as special technical publications (STP Nos. 126 and 122).

At the March meeting of the committee, a Symposium on the Use of Radioisotopes in Soil Mechanics[1] was held at which the following three papers were presented:

Radioisotopes and Nuclear Reactions Applied to Soil Mechanics Problems, by H. E. Hosticka, Bureau of Reclamation, Denver, Col.

Use of Radioactive Material to Measure Soil Moisture and Density, by D. J. Belcher, College of Engineering, Cornell University and R. C. Herner, Chief, Airport Division, GAA Technical Development and Evaluation Center.

Determining Soil Moisture and Density by Nuclear Radiations, by D. A. Lane, J. W. T. Spinks, and B. B. Torchinsky, University of Saskatchewan.

The two following publications were sponsored by the committee and published during the past year by the Society:

Triaxial Testing of Soils and Bituminous Mixtures (STP No. 106), and

Symposium on the Identification and Classification of Soils (STP No. 113).

During the year 11 new members representing individuals or organizations were admitted to the committee. There were eight separations during the year. The committee now consists of a total of 126 members and 17 consultants representing 96 voting memberships. The voting membership consists of 19 producers, 42 consumers, and 35 general interest members.

The death of Mr. E. A. Willis, a valued and long-time member of the committee, on May 10, 1951, was announced at the June meeting.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee D-18 presented to the Society through the Administrative Committee on Standards, recommendations for publication of the following as tentative:

Tentative Method of:

Test to Determine the Bearing Capacity of Soil for Static Loads on Spread Footings (D 1194 - 52 T),

Non-Repetitive Load Test for the Evaluation and Design of Airport and Highway Pavements (D 1195 - 52 T), and

Repetitive Static Load Test for the Evaluation and Design of Airport and Highway Pavements (D 1196 - 52 T).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Issued as separate publication *ASTM STP No. 134.*

These tentative methods were accepted by the Standards Committee on February 15, 1952, and will appear in the 1952 Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the *Tentative Method of Test for Specific Gravity of Soils* (**D 854 – 50 T**)[2] be approved without change for reference to letter ballot of the Society for adoption as standard.[2a]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following six tentatives which have stood for two years or more without revision be continued in their present status without change:

Tentative Definitions of:

Terms and Symbols Relating to Soil Mechanics (D 653 – 42 T),

Tentative Methods of:

Test for Moisture-Density Relations of Soils (D 698 – 42 T),
Testing Soil-Bituminous Mixtures (D 915 – 47 T),
Test for Shear Strength of Flexible Road Surfaces, Subgrades and Fills by the Burggraff Shear Apparatus (D 916 – 47 T),
Test for Amount of Material in Soils Finer than the No. 200 Sieve (D 1140 – 50 T), and
Test for Load-Settlement Relationship for Individual Piles (D 1143 – 50 T).

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following three standards be continued as standard without revision:

Standard Methods of:

Surveying and Sampling Soils for Highway Subgrades (D 420 – 50),
Mechanical Analysis of Soil (D 422 – 51), and
Test of Cement Content of Soil-Cement Mixtures (D 806 – 47).

REAFFIRMATION OF STANDARDS

Committee D-18 recommends that the following nine standards which have stood without revision for six or more years be reaffirmed as standard:

Standard Method of:

Preparing Soil Samples for Mechanical Analysis and Determination of Subgrade Soil Constants (D 421 – 39),
Test for Liquid Limit of Soils (D 423 – 39),
Test for Plastic Limit and Plasticity Index of Soils (D 424 – 39),
Test for Centrifuge Moisture Equipment of Soils (D 425 – 39),
Test for Field Moisture Equivalent of Soils (D 426 – 39),
Test for Shrinkage Factors of Soils (D 427 – 39),
Test for Moisture-Density Relations of Soil-Cement-Mixtures (D 558 – 44),
Wetting and Drying Test of Compacted Soil-Cement Mixtures (D 559 – 44), and
Freezing and Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 44).

The last three standards listed (D 558, D 559, and D 560) are under the joint jurisdiction of Committee D-18 and Committee D-4 on Road and Paving Materials.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee G-2 on Special Papers (M. D. Catton, chairman) arranged for the special papers on the Use of Radioisotopes in Soil Mechanics[1] given at the Spring meeting in Cleveland, Ohio, on March 5, 1952.

Subcommittee G-3 on Nomenclature and Definitions (Charles R. Foster, chairman) has been working on the compilation of terms and symbols used in soil mechanics. The work has been coordinated with the corresponding subcommittee of the American Society of Civil Engineers. It is hoped that a meeting of the subcommittee can be arranged this summer and a joint meeting with the ASCE committee, perhaps during the Centennial in Chicago next September.

Subcommittee G-4 on Evaluation of Data (Douglas McHenry, chairman) has submitted a paper by Glen Balmer entitled, "A General Analytical Solution of Mohr's Envelope."[3]

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[2] 1950 Supplement to Book of ASTM Standards, Part 3.

[2a] This recommendation was submitted to letter ballot of the committee; the results were favorable and the results are on record at ASTM Headquarters.

[3] See p. 1260, this volume.

Subcommittee R-1 on Surface and Subsurface Reconnaissance (L. E. Gregg, chairman).—The activities of the subcommittee have been confined to the completion of the publication containing papers of the Symposium on Surface and Subsurface Reconnaissance presented during the 1951 Annual Meeting. Future work of the subcommittee will be based on problems that will originate from the published material after sufficient study and application to reconnaissance.

Subcommittee R-2 on Borings and Sampling for Soil Investigations (J. O. Osterberg, chairman).—The subcommittee has prepared and submitted to the committee three proposed tentative methods for soil sampling: Method on Borings and Sampling for Soil Investigation of Embankment Materials, Method for Thin-Walled Tube Sampling of Soils, and Method for Split-Tube Sampling of Soils.

Subcommittee R-3 on Physical Characteristics of Soil (Harold Allen, chairman).—Section R-3A is studying a revision of the Method of Test for Amount of Material in Soils Finer Than No. 200 Sieve (D 1140 – 50 T) and Method of Mechanical Analysis of Soil (D 422 – 51).

Section R-3B is studying revisions of the Method of Test for Liquid Limit of Soils (D 423 – 39) and the Method of Test for Plastic Limit and Plasticity Index of Soils (D 424 – 39).

Section R-3C is preparing drafts for the revision of the Methods for the Determination of Moisture-Density Relationships for Soils (D 558 – 44).

Subcommittee R-4 on Physical Properties of Soil (E. S. Barber, chairman).—Work is progressing on development of a test procedure for water permeability of compacted soil. A symposium on permeability for 1953 is being considered. Terminology proposals of the American Standards Association Committee on Fluid Permeation have been discussed.

Subcommittee R-5 on Structural Properties of Soils (D. M. Burmister, chairman).—This subcommittee was responsible for the symposium on Consolidation given during the 1951 Annual Meeting. Section R-5B is arranging and sponsoring the Symposium on Direct Shear Testing of Soils[4] which is being held at the 1952 Annual Meeting.

Subcommittee R-6 on Physico-Chemical Properties of Soils (R. C. Mielenz, chairman).—The energies of the subcommittee have been devoted largely to the preparation and organization of the Symposium on Exchange Phenomena in Soils,[5] scheduled for the 1952 Annual Meeting. The subcommittee has reviewed a procedure for rapid determination of cations in soils prepared by William T. Lambe. The subcommittee also plans to continue in an accelerated manner the development of specific procedures of soil analysis and treatment.

Subcommittee R-8 on Special and Construction Control Tests (H. F. Clemmer, chairman).—Projects to be considered by the subcommittee include the Burggraf Shear Test, California Bearing Ratio, Triaxial Test for Soils, study of Plate Bearing Tests, Moisture-Density Relations of Soils in the Field, further research on the Method of Testing Soil Bituminous Mixtures (D 915 – 47 T), and a method for determining the chloride content of soils.

Subcommittee R-9 on Dynamic Properties of Soil (R. K. Bernhard, chairman).—The revised scope of the subcommittee was approved at the 1951 meeting at Atlantic City. A fifth revision of the list of publications referring to soil dynamics is being prepared by the subcommittee.

Subcommittee R-10 on Bearing Tests of Soil in Place (L. A. Palmer, chairman).—The Method of Testing to Determine the Bearing Capacity of Soil for Static Loads on Spread Footings, (D 1194 – 52 T) is being revised editorially. Section B is planning a symposium on Lateral Load Tests on Piles for the 1953 Annual Meeting.

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[4] Issued as separate publication *ASTM STP No. 131.*

[5] Issued as separate publication *ASTM STP No. 142.*

Joint D-4, D-18 Subcommittee on Tests and Specifications for Stabilized Soils (H. F. Clemmer, chairman) has prepared and accepted a proposed specification for materials for soil aggregates subbase, base, and surface coarses. This proposed specification essentially combines the material in ASTM Specifications D 556 – 40 T and D 557 – 40 T, and brings them in line with the changes recommended by the American Association of State Highway Officials.

MISCELLANEOUS

The Executive Subcommittee at its meetings in January and in March 1952, decided that a paper on ASTM activities should be prepared for the Third International Soil Conference on Soil Mechanics and Foundation Engineering. This paper will be more or less a progress report on Committee D-18 activities covering the period since the Second International Conference. The Executive Subcommittee recommended W. G. Holtz as the Society representative to the conference.

The National Conference on Clays and Clay Technology is to be held in Berkeley, Calif., during the week of July 23–27, 1952. This is being sponsored by the University of California, and the cooperation of ASTM Committee D-18 through Subcommittee R-6 has been requested. The subcommittee is responsible for the program for the session on Clay Technology in Soil Mechanics and will present a paper on relation of physical-chemical properties to engineering performance of soils.

This report has been submitted to letter ballot of the committee which consists of 96 voting members; 50 members returned their ballots, of whom 48 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

E. J KILCAWLEY,
Chairman.

W. G. HOLTZ,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting there was presented to the Society through the Administrative Committee on Standards the recommendation of Committee D-18, jointly with Committee D-4 on Road and Paving Materials, that Specifications for Materials for Soil-Aggregate Subbase, Base and Surface Courses be published as tentative. This recommendation was accepted by the Standards Committee on September 5, 1952, and the new tentative specifications appear in the 1952 Book of ASTM Standards, Part 3, bearing the designation D 1241 – 52 T.

REPORT OF COMMITTEE D-19
ON
INDUSTRIAL WATER*

Meetings of Committee D-19 and of Subcommittees I and III to VII were held June 20 to 22, 1951, in Atlantic City, N. J. and, exclusive of Subcommittee I, on March 5 to 7, 1952, in Cleveland, Ohio. Subcommittees I and II met on October 22, 1951, in Pittsburgh, Pa.

The symposium on Continuous Analysis of Industrial Water and Industrial Waste Water,[1] a committee-sponsored program, is being presented in two sessions on water during the Annual Meeting of the Society in New York, N. Y. The program consists of the following papers:

Introduction to the Symposium, B. W. Dickerson, Engineering Department, Hercules Powder Company, Wilmington, Delaware,

Automatic Sampling of Industrial Water and Industrial Waste Water, M. F. Madarasz, Plant Engineering Office, Ford Motor Company, Detroit, Michigan,

Continuous Recording of Chlorine Residuals and Determination of Chlorine Demand, A. E. Griffin, Director, Technical Services Division, Wallace and Tiernan Company, Inc., Newark, N. J.,

Measurement of Color, Turbidity, Hardness, and Silica in Industrial Waters, F. C. Staats, Hercules Experiment Station, Hercules Powder Company, Wilmington, Delaware,

Continuous Measurement of Dissolved Gases in Water, J. K. Rummel, Senior Engineer, Sheppard T. Powell, Baltimore, Maryland, and

Some Practical Aspects of the Measurement of pH, Electrical Conductivity, and the Oxidation-Reduction Potentials of Industrial Water, Robert Rosenthal, Industrial Instruments, Inc., Jersey City, N. J.

The Guide for the Administration and Operation of Committee D-19 on Industrial Water has been expanded and revised and is being recommended to Headquarters for printing, subject to revisions noted below (see also reports of Subcommittees I and II, which follow). The expanded Guide includes:

Part I.—Regulations Governing Committee D-19 on Industrial Water.

Part II.—Administration and Operation of Committee D-19 on Industrial Water.

Part III.—Recommendations for the Form of ASTM Methods and Specifications Relating to Industrial Water and Industrial Waste Water.

The pertinent changes in the Regulations include the requirements for committee members to maintain membership, changes in the scopes of Committee D-19 and its subcommittees, and the following changes in structure: Subcommittee II, Editorial, is discontinued. The editorial activities will be directed by a standards advisor, who will be a committee-appointed officer and a member of Subcommittee I, Advisory. Subcommittee V on Classification is discontinued. The Section on Stability of Subcommittee VI on Methods of Testing is discontinued. The title of Subcommittee VII is changed to "Industrial Waste Water."

A new Subcommittee II on Definitions and General Specifications has been organized, to include the following sections:

A—ASTM Manual of Industrial Water, transferred from the former Subcommittee II,

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 17–23, 1952.

[1] Issued as ASTM *STP No. 130*.

B—Nomenclature and Terminology, transferred from the former Subcommittee V,
C—Methods of Reporting, and
D—General Specifications, not under the jurisdiction of other subcommittees.

The preceding changes and the following appointments are effective July 1, 1952: Standards Advisor, Claude K. Rice; Chairman, Subcommittee II, S. K. Love; Chairman, Subcommittee VI, Frank N. Alquist, succeeding V. V. Kendall, resigned. The change in the committee scope requires the approval of the Board of Directors,[1] and the following modification has been submitted:

> The study of water as an engineering material; the standardization of terminology and of methods for sampling, analysis, and corrosivity testing of industrial water, industrial waste water, and water-formed deposits; and the formulation of performance (not purchase) specifications.

The Board of Directors also has been requested to declassify the Producer, Consumer, and General Interest members of the committee.[2]

The ASTM Manual of Industrial Water,[3] a committee-sponsored project for the past five years, is being recommended to the Society for publication at the conclusion of the final editing, now in progress. The manual includes the following chapters:

Uses of Industrial Water,
Difficulties Caused by Water in Industry,
Composition of Industrial Water and Water-Formed Deposits,
Treatment of Industrial Water,
Sampling of Industrial Water,
Analysis of Industrial Water,
Sampling and Identification of Water-Formed Deposits,
Analysis of Water-Formed Deposits, and
Appendix (including glossary and tables).

All of the methods and specifications prepared under the jurisdiction of Committee D-19 and approved by the Society will be published in the manual.

The American Public Health Association has accepted an invitation to membership on Committee D-19. This addition is a continuation of the policy having for its objective the uniformity of standard methods for the examination of water. The A.P.H.A. representatives designated and elected are F. Wellington Gilcreas (Chairman of A.P.H.A. Subcommittee on Standard Methods for the Examination of Water and Sewage) and Paul Kabler. Frank E. Clarke, chairman, Subcommittee IV on Methods of Analysis, and Roy F. Weston, chairman, Section B, Analysis, Subcommittee VII have been designated as the ASTM representatives to serve on the abovementioned A.P.H.A. subcommittee.

The Executive Committee, Joint Research Committee on Boiler Feed Water Studies, on which F. N. Speller and Max Hecht serve as the ASTM representatives, held a meeting on November 30, 1951, in Atlantic City, N. J. which was attended by the latter. (The ASTM is one of seven sponsoring societies.) The officers of the Joint Research Committee are preparing a summary of the activities of their committee, which will be published later this year in the ASTM BULLETIN.

The Chemical Section of the Subcommittee on the Care of Pressure Vessels in Service, A.S.M.E. Boiler Code Committee, on which Max Hecht serves as Committee D-19 representative, held no meetings in 1951. The representative filed a negative vote July 10, 1951, directed to the contents of "Suggestions for the Care of Power Boilers, Sixth Draft, March 1, 1951, A.S.M.E. Boiler Construction Code," as per instructions voted by both the members of Subcommittee I Advisory and Committee D-19 on June 21 and 22, 1951. The contents of the Sixth Draft are intended as revisions to the currently published Section VII of the A.S.M.E. Boiler Construction Code. The officers of Committee D-19 are currently studying proposals for ASTM preparation of non-referee procedures for use in field control analysis of water which, when available, are intended to replace the various procedures now included in the appendix of the Sixth Draft.

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[2] Approved by the Board of Directors at its meeting May 6, 1952.

[3] Issued as separate publication *ASTM STP No. 148.*

L. Drew Betz, serving as the ASTM representative on the Federation of Sewage Works and Industrial Waste Associations, reviewed a compilation of methods and revisions prepared by the Federation's Committee on Standard Methods of Sewage and Industrial Waste Analysis, W. D. Hatfield, chairman. This compilation of methods is intended for publication in the forthcoming tenth edition of Standard Methods for Examination of Water, Sewage and Industrial Waste (A.P. H.A.).

The selection of officers to serve for the ensuing term of two years has resulted in the election of the following:

Chairman, Max Hecht.
Vice-Chairman, Robert C. Adams.
Vice-Chairman, F. R. Owens.
Secretary, R. T. Sheen.

At present there are 107 members serving on Committee D-19.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Recommendations were submitted to the Administrative Committee on Standards at its meeting on September 12, 1951, which resulted in the acceptance as tentative of the following two proposed specifications and the continuation of one revised method:

Tentative Specifications for:

Equipment for Sampling of Industrial Water and Steam (D 1192 - 51 T),
Reagent Water (D 1193 - 51 T), and

Tentative Method of:

Sampling Water from Boilers (D 860 - 51 T) for continuation as tentative, with revisions.

The new and revised tentatives appear in the 1951 Supplement to Book of ASTM Standards, Part 5.

PROPOSED METHOD TO BE PUBLISHED AS INFORMATION

Committee D-19 recommends that the following proposed method be published as information, as appended hereto:[4]

Proposed Method of Sampling Steam and Water at Subatmospheric Pressure.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard, without revision:

Tentative Specifications for:

Substitute Ocean Water (D 1141 - 50 T),[5]

Tentative Method for:

Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction (D 934 - 50 T),[5] and
Nitrate Ion in Industrial Water (D 992 - 48 T).[6]

REVISIONS OF STANDARDS FOR IMMEDIATE ADOPTION

The committee recommends for immediate adoption the revision of the two following standards:

Method of Test for Calcium Ion and Magnesium Ion in Industrial Water (**D 511 - 42**)[6] with the following revision: Change Section 3 (*i*) to read as follows: "Soluble Methyl Red Indicator"; and

Standard Method of Corrosivity Test (USBM Embrittlement Detector Method) (**D 807 - 49**),[6] revision appended hereto.[7]

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[4] See p. 503.
[5] 1950 Supplement to Book of ASTM Standards, Part 5.
[6] 1949 Book of ASTM Standards, Part 5.
[7] The revisions were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 7.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends the continuation of the following ten tentatives without revision, pending further study:

Tentative Method of Test for:

Total Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Water (D 513 - 50 T),
Silica in Industrial Water (D 859 - 50 T),
Dissolved Oxygen (D 888 - 49 T),
Suspended and Dissolved Solids in Industrial Water, (D 1069 - 49 T),
Electrical Conductivity of Industrial Water (D 1125 - 50 T),
Hardness in Industrial Water (D 1126 - 50 T),
Sodium and Potassium in Industrial Water (D 1127 - 50 T),
Iron in Industrial Water (D 1068 - 49 T),

Tentative Methods of:

Sampling Steam (D 1066 - 49 T), and
Tentative Method for the Identification of Types of Microorganisms in Industrial Water (D 1128 - 50 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[8]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I, Advisory (Max Hecht, chairman).—The subcommittee accepted the report of the Task Group on Papers of Committee D-19 and recommended to the Society the presentation of the program mentioned earlier in this report. The task group consists of B. W. Dickerson (chairman), A. A. Berk, C. E. Kaufman, and Claude K. Rice. The report of the Nominations Task Group was submitted to Committee D-19 at the meeting March 7, 1952, at which time it was approved. (The incumbent officers were nominated.)

The proposed revisions to the Regulations Governing Committee D-19 on Industrial Water, prepared by F. R. Owens, were considered and distributed to the committee for letter ballot. The regulations dated February 1, 1952, were approved by the committee. The proposed revisions of Recommendations on the Form of ASTM Methods and Specifications Relating to Industrial Water and Industrial Waste Water, prepared by Claude K. Rice, were approved on March 5, 1952. Recommendations for the printing of the revised and expanded Guide were submitted to the Society.

The subcommittee recommended to the Administrative Committee on Standards adoption of the methods and specifications listed earlier in this report.

Subcommittee II, Editorial (Claude K. Rice, chairman).—The subcommittee gave editorial approval to the proposed revisions of the Standard Method of Corrosivity Test (USBM Embrittlement Detector Method) (D 807 - 49) as appended hereto.[7] Also approved were drafts of the proposed Methods of Test for Cupric Ion, and Methods for Examination of Water-Formed Deposits by Chemical Microscopy. Drafts of proposed Methods of Test for Nitrite Ion, for Bromide and Iodide Ions, and for Residual Chlorine were editorially reviewed and returned to Subcommittee IV with suggestions for improvement in form.

Titles and scopes for the following eleven proposed methods were editorially approved and returned to Subcommittee VII: Chemical Oxygen Demand, Chlorine Demand, Dissolved Solids, Suspended Solids, Cyanides, Sulfur Compounds, Odor, Oily Matter, pH, Phenolic-Type Compounds, and Toxicity to Aquatic Life.

Review was made of galley and page proof of the methods prepared by Committee D-19 in 1951 and 1952.

Section A on ASTM Manual of Industrial Water has the manual in the final stages of preparation. It is anticipated that the finally edited manuscripts of the chapters together with illustrations will be delivered to the Society for publication prior to the Society Annual Meeting, June, 1952, and that publication of the compilation will be made before the end of 1952.

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[8] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Each section member has been provided with draft copies of all of the chapters, for final corrections. The Committee D-19 members who have cooperated as authors on this project are:

R. C. Adams, Editor, U. S. Navy Engineering Experiment Station, Annapolis, Md.
A. A. Berk, Industrial Water Branch, U. S. Bureau of Mines, College Park, Md.
T. H. Daugherty, Calgon Inc., Pittsburgh, Pa.
Orrin M. Elliott, Sun Oil Co., Philadelphia, Pa.
J. A. Holmes, National Aluminate Corp., Chicago, Ill.
C. E. Imhoff, Research Department, Allis Chalmers Mfg. Co., Milwaukee, Wisconsin.
A. K. Light, National Research Council of Canada, Ottawa, Ontario, Canada.
F. U. Neat, Consolidated Gas Electric Light and Power Co. of Baltimore, Baltimore, Md.
F. R. Owens, Cyrus W. Rice and Co., Inc., Pittsburgh, Pa.
A. H. Reynolds, Dearborn Chemical Co., Chicago, Ill.

Subcommittee III, on Methods of Sampling (Orrin M. Elliott, chairman).—The subcommittee prepared the revised Tentative Method of Sampling of Water from Boilers (D 860 – 51 T), and the Tentative Specifications of Equipment for Sampling Industrial Water and Steam (D 1192 – 51 T), which were approved by letter ballot of the committee, and accepted for the Society by the Administrative Committee on Standards. The Tentative Method of Sampling of Steam (D 1066 – 49 T) was recommended for continuation with no revisions, pending further study.

The subcommittee has in progress a revision of the Standard Methods of Sampling Industrial Water (D 510 – 49). The revision includes the insertion of references to the Tentative Specifications for Equipment for Sampling Industrial Water and Steam (D 1192 – 51 T) and the deletion of references to equipment as now shown, and the inclusion of new sections for the sampling of water for biological examination. A necessary notation will be provided in the revision for the sampling of potable water for bacteriological examination, referring to the Standard Methods for Examination of Water, Sewage and Industrial Waste, A.P.H.A. in the forthcoming tenth edition. A Proposed Method of Sampling Steam and Water at Subatmospheric Pressures has been prepared, and is appended[4] to this report for information.

Subcommittee IV, on Methods of Analysis of Industrial Water (Frank E. Clarke, chairman). — The subcommittee submitted the following recommendations which were approved by the committee, and these are being submitted to the Society for adoption: Tentative Method for Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction (D 934 – 50 T), with no revisions, and Tentative Method of Test for Nitrate Ion in Industrial Water (D 992 – 48 T). Recommendation was made to continue as standard, with revisions, the Method of Test for Calcium Ion and Magnesium Ion in Industrial Water (D 511 – 42). The subcommittee recommended the continuation of the tentatives listed earlier in this report, with no revisions, for further study. The subcommittee completed preparation of the following four new proposed methods which, when letter ballot is secured, will be subject to submission to the Administrative Committee on Standards for acceptance as tentative: Method for the Examination of Water-Formed Deposits by Chemical Microscopy, Methods of Test for Bromide and Iodide Ions in Industrial Water, Methods of Test for Residual

Chlorine in Industrial Water, and Method of Test for Nitrite in Industrial Water. A Proposed Method of Test for Cupric Ion in Industrial Water which had been submitted to the committee for letter ballot, has been returned to the subcommittee for reconsideration.

Among the task groups comprising Section A, substantial progress is reported in the groups on Tyndall Effect (Nephelos Number), Hardness (a colorimetric titration procedure), Hydrogen Sulfide, and Master Scheme for Analysis of Water. Work is progressing on the revision of the Standard Method of Test for Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Water (D 515 – 43). Revisions to the Tentative Methods of Test for Dissolved Oxygen in Industrial Water (D 888 - 49 T), will be made at the conclusion of a broad series of test runs to be made at a steam station by members of the task group. Editorial revisions are being considered for the Tentative Method of Test for Iron in Industrial Water (D 1068 - 49 T).

Two new task groups have been organized: Sulfite, J. K. Rummel (Chairman), A. A. Berk, Frank N. Alquist, L. D. Betz, and Frank Henry; and Task Group for Ammonia, chairman to be appointed, with the following members, W. A. Lower, T. E. Ellis, and C. C. Ruchhoft.

The following task group chairmen have been appointed succeeding former chairmen, resigned: W. L. Lamar, on Fluoride Method; J. Prescott, on Hardness Method.

Section B on Electrometric Methods has in preparation a Proposed Method for Oxidation-Reduction Potentials in Industrial Water (also for use in industrial waste water). There is under consideration a proposed revision of the Tentative Method of Test for Electrical Conductivity of Industrial Water (D 1125 – 50 T), the revision consisting of a non-referee procedure. Additional revision as may be required for the use of this method in industrial waste water also will be considered.

Robert Rosenthal was appointed the section chairman, succeeding F. H. Perley, resigned.

Section C on Special Methods has completed the preparation of the Chemical Microscopy method previously mentioned in this report. The X-Ray Diffraction method mentioned in the recommendations of this report is being revised only as to form, and this repreparation is also being done to the Tentative Method of Identification of Types of Microorganisms in Industrial Water (D 1128 – 50 T). Progress reports have been made on the status of proposed methods for Spectroscopy and Flame Photometry.

Work is continuing by Section D on the preparation of Methods for the Examination of Water-Formed Deposits by Chemical Analysis. The task group is developing a broad test program for the verification of the various procedures that are intended for this method.

Subcommittee V, on Classification (S. K. Love Chairman).—The subcommittee completed preparation of the Tentative Specifications for Reagent Water (D 1193 – 51 T). The subcommittee is considering proposed revisions to these specifications, by the addition of requirements for Organic Matter and the Tyndall Effect applying to both grades as specified. The preparation of ion-free or substance-free water will be described in the specific method, where this requirement is found necessary.

Subcommittee V on Classification will be cancelled from the committee structure, effective June 30, and is reorganized, as Subcommittee II. The section on Classification has been cancelled from the projects of the committee due to inactivity. The cancellation was approved by Committee D-19 at the March 7 meeting.

R. J. Austin has been appointed chairman of the Task Group for Reagent Water, succeeding M. D. Baker, resigned.

Subcommittee VI, on Methods of Testing (V. V. Kendall, chairman).—The subcommittee completed the proposed revision of the Standard Corrosivity Test Embrittlement Detector Method (D 807). The revised method is appended to this report.[7] The subcommittee and the Advisory Committee on Corrosion recommended advancement to Standard of the tentative Specifications for Substitute Ocean Water (D 1141 - 50 T), with no revisions. The subcommittee recommends cancellation of the Section on Stability due to inactivity. This recommendation was approved by Committee D-19 on March 7, 1952.

The Task Group on Service Testing of Tubular Materials reports progress on an assignment of nipple specimens. Enclosed in a small size heat exchanger, the specimens are subjected to the water supply and plant operating conditions for the observation of corrosivity and deposit-forming characteristics of water. The heat exchanger unit is located in a by-pass line, thus permitting frequent inspections of the specimens without the necessity of a complete plant shut-down. Data which has been secured from these installations in various geographic areas is being assembled. The design of the equipment together with the data will be made available in a subsequent report of this committee, when a proposed Method of Corrosivity Test has been prepared.

Subcommittee VII, on Industrial Waste Water (L. Drew Betz, chairman).—Section A on Critical Constituents in Industrial Waste Water is continuing its work in the listing of various industries by groups, and in ascertaining the constituents of waste water common to these industries. Roy F. Weston, in his work of compiling a list of trade organizations having committees on waste disposal, has been directed to supply Section A with a copy of his compilation. Contact with such trade organizations is contemplated in order to enlarge the list of critical constituents common to all industries.

Titles and scopes of eleven proposed methods of testing industrial waste water were prepared and editorially approved by Section B on Analytical Methods. (Refer to report of Subcommittee II.) The section's task groups are proceeding with the preparation of the substance of these methods. Section B now has a total of twelve task groups, each actively engaged in the preparation of methods for specific constituents or substances present in an industrial waste water.

It is anticipated that the following five proposed methods of analysis will be distributed to the committee prior to the Annual Meeting, for letter ballot approval of their publication as tentative: Suspended Solids (Matter), Chemical Oxygen Demand, Chlorine Demand, Oily Matter, and Sulfur Compounds.

The Task Group on Sampling and Gaging of Section C is studying statistics as applied to small samples, together with a report on "Sampling and Measuring Industrial Waste," H. H. Black, U. S. Public Health Service, Cincinnati, Ohio, published in "Sewage and Industrial Waste, January 1952" in preparation of the section's proposed Method for Sampling and Gaging Industrial Waste Water.

Section D on Methods of Reporting Results is working on the development of reporting results obtained by specific methods of analysis where such may be required, in close cooperation with Section B on Analytical Methods. Replies to a questionnaire, to ascertain the manner of reporting analyses of industrial waste water, showed that there is a preponderant desire by industry to maintain the use of parts per million (ppm) in reporting these analyses. A small portion of the replies showed a preference for reporting the analyses in per cent by weight, and in milligrams per liter.

W. D. Hatfield (chairman), Committee on Standard Methods of Sewage and Industrial Waste Analysis, Federation of Sewage and Industrial Waste Associations, advised that in the tenth edition of Standard Methods for the Examination of Water, Sewage and Industrial Waste (A.P.H.A.), the statement will probably be made that analytical data may be reported in micrograms per liter, or parts per billion (ppb), and milligrams per liter, or parts per million (ppm). This Section's recommendations for reporting are appended to this report[9] and published for information only.

This report has been submitted to letter ballot of the committee, which consists of 107 members; 73 members have returned their ballots, of whom 62 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

R. T. SHEEN,
Secretary.

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[9] See p. 505.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-19 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of:

Test for Iodide and Bromide Ions in Industrial Water (D 1246 - 52 T).

Tentative Method for:

Examination of Water-formed Deposits by Chemical Microscopy (D 1245 - 52 T).

Revision of Tentative Specifications for:

Reagent Water (D 1193 - 51 T).

These recommendations were accepted by the Standards Committee on September 5, 1952, and the new and revised tentatives appear in the 1952 Book of ASTM Standards, Part 7.

APPENDIX I

PROPOSED METHOD OF SAMPLING STEAM AND WATER AT SUBATMOSPHERIC PRESSURE[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method covers the basic requirements of apparatus and procedure for obtaining a representative sample of steam or water at pressures below atmospheric. The method covers the extraction of the sample and delivery to the point of analysis.

Application

2. (*a*) This method applies to streams of fluid at low pressures, such as those issuing from low-pressure evaporators, turbine bleed steam, and condensed water from heaters, condensers, and process steam condensate.

(*b*) The method in general is similar to the Tentative Method of Sampling Steam (ASTM Designation: D 1066),[2] except as it must be modified by the requirement that means must be provided for extraction of the samp against the higher atmospheric pressure.

Apparatus

3. (*a*) The essential apparatus consists of a sampling nozzle, a condensing coil, a cooling coil, and a suitable receiver for collection of the sample or a flow chamber through which the condensed steam or cooled water sample may be passed over suitable measuring and analytical devices.

(*b*) The sampling nozzle may be essentially the same and based on the same principles as for the nozzle specified in Method 1066. The condensing or cooling coil specifications may also be the same as specified in Method D1066 and the Tentative Specifications for Equipment for Sampling Industrial Water and Steam (ASTM Designation: D 1192).[3] An additional requirement is that means should be provided for measuring the temperature rise and rate of flow of the cooling water. This is necessary as a means of measuring the rate of flow of the sample. The cooling water should be of the lowest available temperature.

(*c*) The steam sampling nozzle shall be of a material equal in quality to the material of the conduit through which the stream being sampled flows. The condenser and cooling coil shall be located as close as possible to the sampling nozzle.

(*d*) The material of the condenser or cooler shall be of alloy resistant to any chemical attack by the fluid being sampled. This same requirement applies to the line from the condenser cooler to and including the sample container.

(*e*) The principal problem in sampling fluid at subatmospheric pressure is the extraction of a sample from a region of subatmospheric pressure and delivering it to a container at atmospheric pressure. Several proposed means of creating flow of fluid through the sampling system are offered as alternates, as follows:

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-19 on Industrial Water. Published as information, June, 1952.

[2] 1949 Book of ASTM Standards, Part 5.

[3] 1951 Supplement to Book of ASTM Standards, Part 3.

(*1*) An atmospheric leg, where sufficient height is available. From the bottom of such a leg the sample may flow to atmospheric pressure through a conductivity cell chamber or to a container. It is not advisable to elevate the line from the sampling nozzle to obtain height for an atmospheric leg because of condensation and reverse drip in the upwardly extended line.

(*2*) A small condensate pump, preferably a diaphragm-type, controlled by the level in a collecting chamber.

(*3*) Vacuum pumps, either mechanical or fluid-jet type, controlled to maintain a differential pressure across the sampling system.

(*4*) Tapping into the steam line at a point downstream from the sampling nozzle. The ports of the sampling nozzle, facing upstream serve as an impact nozzle. The downstream tap could be a reversed nozzle in order to obtain maximum pressure difference. The downstream connection should be provided with a throttle valve to control sample flow rate. The sample-collecting receiver may be of glass or provided with a sight glass so that the rate of condensate flow may be observed. When this is not possible or desirable, the rate of sample collection may be determined by the cooling water flow rate and its temperature rise.

(*5*) Possibly, collection of the sample into a "dead-end" receiver. The receiver could be provided with a tap connected to an evactor, such as a fluid-jet type which would be used only to scavenge the system of air at the start of the sampling period with the expectation that sufficient flow of sample would result from condensation and cooling.

(*f*) In Paragraph (*e*) it is assumed that a bulk sample is required for a laboratory analysis. The sampling receiver should be of sufficient volume for the required sample. The condensate pump would deliver the sample to a receiver at atmospheric pressure. With the last three alternative means of creating flow listed above the receiver would be valved off from the collecting system at the end of a sampling period, equalized to atmospheric pressure through a protective train, and drained into a suitable receiver. When conductometric methods of analysis only are required, a continuous flow through the electrode chamber could be provided, the drips being returned to the steam main at the point of the low-pressure tap or discarded to waste by pump or ejector.

Point of Sampling

4. The sampling nozzle should be located at a point in the fluid stream being sampled after as long a straight section of conduit as possible. A minimum of ten diameters is recommended. This is particularly important when steam is sampled.

Procedure

5. (*a*) Establish a flow through the sampling system, preferably at a minimum rate of 50 lb per hr. This recommendation will be modified by the pressure at which steam is sampled and the limitation imposed by the sampling nozzle proportions as compared with the conduit in which the stream being sampled flows.

(*b*) The condensed or cooled effluent should be discarded until the lines and cooling system are completely flushed out, as determined by conductivity or other measurement.

(*c*) When bulk samples are taken for laboratory analysis, extreme care must be taken to avoid contamination, and the samples should be processed in the laboratory without delay.

APPENDIX II

SUGGESTED GENERAL SYSTEM FOR REPORTING TEST DATA ON INDUSTRIAL WASTE WATER

(Published as information only.)

Subcommittee VII, of Committee D-19, suggests the following system for reporting test data on industrial waste water:

In parts per billion (ppb)[a]	from 0 to 1 000
In parts per million (ppm)	from 1 to 10 000
Per cent by weight	10 000 ppm and over

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[a] The term "billion" is intended to mean 10^9.

In reporting per cent by weight, it shall be so specified, and the specific gravity of the liquid shall be stated if it differs from 1.0.

For determinations of "residue on evaporation" (dissolved solids or matter) the temperature of 103 C, or the temperature at which the constant weight was obtained, shall be given in the report. In reporting the content of volatile matter, it shall be stated if the data reported is by volume or by weight, and if by volume the temperature and the pressure shall be stated.

Report results of "settleable solids" by the Imhoff cone method as milliliters per liter (ml per l).

Report "hydrogen ion concentration" as "pH" and state the temperature of observation.

REPORT OF COMMITTEE D-20

ON

PLASTICS*

Committee D-20 on Plastics, and its subcommittees, held three meetings during the year: at Atlantic City, N. J., on June 20 and 21, 1951; in Niagara Falls, Ontario, Canada, on November 12 and 13, 1951; and in Philadelphia, Pa. on February 25 and 26, 1952. The Advisory Committee also met at these meetings.

The committee was represented at the meeting of Technical Committee 61 on Plastics of the International Standards Organization held on September 18 and 19, 1951, in New York City. A number of delegates from various foreign countries also attended this meeting. It was decided at this meeting to have working parties formed from various countries which would undertake assignments in the form of recommended international standards. A meeting of ISO/TC/61 will be held in Turin, Italy, on October 2 to 5, 1952. This meeting follows the Fourth International Congress on Plastics to be held September 29 to October, 1952, in the same city.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. K. Witt.
First Vice-Chairman, W. A. Zinzow.
Second Vice-Chairman, F. W. Reinhart.
Recording Secretary, G. M. Armstrong.
Membership Secretary, B. L. Lewis.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, the following recommendations were presented to the Society through the Administrative Committee on Standards by Committee D-20 jointly with Committee D-9:

Tentative Specifications for:

Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 – 52 T), and
Cellulose Acetate Sheet and Film for Primary Insulation (D 1202 – 52 T).

Revision of Tentative Specifications for:

Laminated Thermosetting Materials (D 709 – 49 T).

Withdrawal of Specifications for:

Phenolic Laminated Sheet for Radio Applications (D 467 – 44),
Round Phenolic Laminated Tubing for Radio Application (D 616 – 41 T),
Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 – 49), and
Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 – 49).

The revision of D 709 – 49 T and the withdrawal of D 467 – 44 T and D 616 – 41 T were accepted by the Standards Committee on February 15, 1952; the other recommendations were accepted on April 4, 1952. Tentative Specifications D 1197 – 52 T and revised Tentative Specifications D 709 – 49 T will appear in the 1952 Book of ASTM Standards, Part 6.

On April 4, 1952, the Administrative Committee on Standards accepted the following recommendations submitted by Committee D 20:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Tentative Specifications for:

Polyester Molding Compounds (D 1201 – 52 T).

Tentative Method of:

Test for Volatile Loss from Plastic Materials (D 1203 – 52 T), and

Measurement of Changes in Linear Dimensions of Nonrigid Thermoplastic Sheeting and Film (D 1204 – 52 T).

Revision of Tentative Specifications for:

Vinylidene Chloride Molding Compounds (D 729 – 44 T),

Revision of Tentative Method of:

Test for Compressive Strength of Plastics (D 695 – 49 T), and

Test for Brittle Temperature of Plastics and Elastomers (D 746 – 44 T).

Tentative Revision of Standard Method of:

Test for Diffusion of Light by Plastics (D 636 – 43), and

Test for Luminous Reflectance, Transmittance and Color of Materials (D 791 – 50).

The new and revised tentatives and tentative revisions of standards will appear in the 1952 Book of ASTM Standards, Part 6.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is presenting for publication two new tentatives, and is recommending the revision of three tentatives, adoption as standard of two tentatives, and reaffirmation of seven standards. The standards and tentatives affected, together with the revisions recommended, are listed in detail in the Appendix to this report.

The committee has considered all of the other tentatives not mentioned in the Appendix, which are under its jurisdiction and which have been issued for two years or longer, and recommends that they be continued in their present status until further revisions in them are made as contemplated.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Properties (M. E. Marks, chairman).—The Section on Tensile and Compressive Strength has recently completed the revision of the Tentative Method of Tests for Compressive Strength of Plastics (D 695 – 52 T). This section is also making a round-robin study of tests for rods and tubes. The Tentative Method of Test for Tensile Properties of Thin Plastic Sheets and Films (D 882 – 49 T) is under further investigation. It is expected that the results from round-robin studies on ski ball tests will shortly be completed. The Section on Dynamic Properties is compiling a nomenclature in connection with this project. A round-robin study will soon be started which will include several types of machines on various grades of plastics.

Subcommittee II on Hardness (R. K. Witt, acting chairman).—The round-robin tests have been completed by the section studying abrasion resistance (mechanical effects) and a method will soon be submitted to the subcommittee for ballot.[2] Analysis of data in reference to the Tentative Method of Test for Resistance of Transparent Plastics to Surface Abrasion (D 1044 – 49 T) has not been completed but definite recommendations to revise this tentative will be made shortly.

Subcommiteee III on Thermal Properties (E. B. Cooper, chairman).—Work has been completed on the proposed new Tentative Method for the Measurement of Flow of Thermoplastics by Extrusion Plastometer and is being recommended as outlined in this report. The Section on the Effect of Heat is working towards tests for softening point, maximum use temperatures, and the annealing of specimens for heat distortion tests. Further work is being contemplated by the Section on Low-Temperature Brittleness in order to improve the Tentative Method of Test for Brittle Temperature of Plastics and Elastomers (D 746 - 52 T).

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[2] See Editorial Note, p. 510.

Subcommittee IV on Optical Properties (H. K. Hammond, 3rd, chairman).—The Section on Color and Color Difference is, at the request of the Society of the Plastics Industry, developing a method of determining small color differences. The SPI has a tentative specification for perceptible and acceptable color differences in terms of blue chips. The Tentative Method of Test for 60-deg Specular Gloss of Paint Finishes (D 523 - 48 T), as prepared by Committee D - 1 on Paint, Varnish, Lacquer and Related Products, has now changed the title of its method so that it is applicable to plastics. The Tentative Method of Test for Haze and Luminous Transmittance of Transparent Plastics (D 1003 - 49 T) has been recommended for adoption as standard.

Subcommittee V on Permanence Properties (W. C. Goggin, chairman).—This subcommittee has completed the Tentative Method of Test for Volatile Loss from Plastic Materials which was accepted by the Standards Committee. The Section on Effect of Water is still studying the water permeability methods and it is expected that a method will be submitted to the subcommittee shortly. It is hoped that this new method will replace the Method of Test for Water Vapor Permeability of Plastic Sheets (D 697 - 42 T). The Section on Effect of Chemicals has completed a proposed Tentative Method of Test for Resistance of Plastic Film to Extraction by Chemicals as submitted in this report. It has been brought to the attention of the subcommittee that a standard method of test for determining the fungus resistance of plastic should be studied and a method developed. It is expected that the subcommittee will select a method applicable to both industry and government agencies. A new Section on Outdoor Weathering has been formed and a chairman will shortly be appointed.

Subcommiteee VI on Specifications (Lucius Gilman, chairman).—This subcommittee is preparing some new tentative specifications and is also working on revisions of a number of the present specifications. The Section on Phenolic Molding Materials expects to prepare a revision of the Specifications for Phenolic Molding Compounds (D 700 - 49 T) in the very near future.[2] These revisions include altering the description of several of the fillers as well as adding other fillers which have come to the section's attention recently. The Section on Vinyl Plastics is studying a number of revisions in various specifications which come under its jurisdiction. The Specifications for Methacrylate Molding Compound (D 788 - 48 T) will shortly be revised as well as the Tentative Specifications for Polystyrene Molding Compounds (D 703 - 49 T). Specifications for Cellulose Acetate Sheet and Film for Primary Insulation (D 1202 - 52 T) prepared by the Section on Cellulose Acetate Plastics has been accepted through the Standards Committee. These specifications were submitted jointly with Committee D-9 on Electrical Insulating Materials. A revision of the Tentative Specifications for Ethyl Cellulose Molding Compounds (D 787 - 46 T) has been completed and is being recommended in this report. The Tentative Specifications for Nylon Injection Molding Compounds (D 789 - 44 T) are under revision, and new proposed specifications for polyethylene are under consideration.[2] The Section on Plasticizers is preparing Specifications for

Dioctyl Phthalate Plasticizers containing three grades. It is expected that these new proposed specifications will be shortly submitted to letter ballot of the subcommittee.[2]

Subcommittee VII on Analytical Methods (D. E. Northrop, chairman).—Work is still proceeding on a method of test for all of the important analytical characteristics of vinyl plastic materials. It is also expected that a method for the extraction of plasticizer from plastics will shortly be forwarded to the members for comment. There are several methods being used but none seem too ideal for all the present cases. The most widely used one probably will be recommended to the subcommittee for study. The Section on Plasticizers is trying to standardize on a heat block.

Subcommittee VIII on Research (C. R. Stock, chairman) is still acting in an advisory capacity on research problems and assisting various educational institutions when required. At the November, 1951, meeting of the subcommittee, the following three papers were presented:

Volumetric Measurements on Molten Polymers, by E. B. Cooper and J. P. Tordella of E. I. duPont de Nemours and Co., Inc.,
Measurement of Residual Stress in Thermosetting Plastics, by R. DeWaard and T. Alfrey, Jr. of the American Cynamid Co., and
Long-Time Relaxation of some Rubber-Like Polymers, by I. L. Hopkins of the Bell Telephone Laboratories.

At the February, 1952, meeting of this subcommittee the following two papers were presented:

Some Observations on Crazing of Acrylic Plastics, by B. M. Axilrod, M. A. Sherman, and I. Wolock of the National Bureau of Standards, and
The Use of Statistics in Chemical Experimentation, by W. L. Gore, of the E. I. duPont de Nemours and Co., Inc.

Subcommittee IX on Molds and Molding Processes (J. L. Williams, chairman).—This subcommittee is studying the Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials (D 1046 - 49 T) as to the possibility of changing the gating and also for the use of high-frequency heating, if it can be successfully applied. There is also under consideration an additional mold shrinkage test specimen. Questionnaires are being circulated within the subcommittee for a new mold shrinkage test method using various wall thicknesses and diameter changes.

Subcommittee X on Definitions, Nomenclature and Significance of Test (C. H. Alexander, chairman).—Various terms and definitions relating to plastics are still being added to the Definitions of Terms Relating to Plastics (D 883 - 49 T). It is expected that a revision of the Recommended Code for Designating Form of Material and Direction of Testing Plastics (D 1009 - 49 T) will be ready in the very near future.

The Section on Correlation of Terms and Definitions prepared the revised definitions of terms relating to tension testing in cooperation with Committee E-1. The work of this subcommittee with E-1 should be of interest to other committees of the Society, since it is believed that the Definition of Terms Relating to Methods of Test (E 6 - 36) should be revised to apply to most of our present-day materials.

Subcommittee XIV on Conditioning (A. C. Webber, chairman).—This subcommittee has completed its work on the Tentative Specifications for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 - 52 T) which were recently recommended to the Standards Committee. Further work is being done on the maintenance and measurement of humidity. All methods of measurement of relative humidity are still being studied, and the material will be later submitted to the subcommittee. It is hoped that all other subcommittees of the Society can supply information to this subcommittee along these lines for their information. The work of this subcommittee is a joint activity with Committee D-9.

This report has been submitted to letter ballot of the committee, which consists of 151 members; 98 members returned their ballots, of whom 89 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. M. KLINE,
Chairman.

B. L. LEWIS,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-20 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Test for Resistance to Abrasion of Plastic Materials (D 1242 - 52 T), and
Test for Specific Viscosity of Vinyl Chloride Polymers (D 1243 - 52 T).

Tentative Specifications for:

Polyethylene Molding and Extrusion Materials (D 1248 - 52 T), and
Primary Octyl Phthalate Ester Plasticizers (D 1249 - 52 T).

Revision of Tentative Specifications for:

*Phenolic Molding Compounds (D 700 - 49 T).

Revision and Reversion to Tentative of:

Standard Method of Test for Resistance of Plastics to Chemical Reagents (D 543 - 43).

These recommendations were accepted by the Standards Committee on December 12, 1952, and the new and revised tentatives appear in the 1952 Book of ASTM Standards, Part 6.

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*Jointly with Committee D-9 on Electrical Insulating Materials.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON PLASTICS

In this Appendix are listed two new tentatives, and proposed revisions in three tentatives covering plastics which are recommended as referred to earlier in this report. In addition, it includes recommendations for the adoption as standard of two tentatives and the reaffirmation of seven standards. The tentatives and standards in their present form appear in the 1949 Book of ASTM Standards, Part 6, and its 1950 and 1951 Supplements, as indicated by the final number of the ASTM designation.

NEW TENTATIVES

Committee D-20 recommends the following two proposed methods for publication as tentative by the Society as appended hereto:[1]

Tentative Method for Measuring the Flow of Thermoplastics by Extrusion Plastometer:

The committee is recommending this method, since it is applicable to extrusion molding grades of thermoplastic materials, especially for addition polymers. This method produces a "melt index" when applied to polyethylene under certain test conditions.

Tentative Method of Test for Resistance of Plastic Films to Extraction by Chemicals:

This method is being recommended for publication, since there is a definite need for determining the weight loss of film after immersion in chemicals. This method is intended to determine this factor for plastic film which is commonly used in household wares.

REVISION OF TENTATIVES

The committee recommends revision in the following three tentatives:

Tentative Specifications for Ethyl Cellulose Molding Compounds (D 787 – 46 T):

These specifications are being revised to provide better agreement with present industrial practice, as appended hereto.[2]

Tentative Definitions of Terms Relating to Plastics (D 883 – 51 T):

Many definitions as prepared by Committee D-14 on Adhesives are applicable to plastic materials and are being recommended for inclusion in D 883, as appended hereto.[2]

Method of Test for Tensile Properties of Plastics (D 638 – 49 T):

The committee recommends that this method be revised as follows:

Section 2.—Omit the definitions in this section and substitute a reference to the revised definitions to appear in the Appendix.

Explanatory Notes.—Omit Note 14.

Appendix.—Revise the definitions of terms and symbols relating to tension testing of plastics as appended hereto.[2]

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[1] The new tentatives were accepted by the Society and appear in the 1952 Book of ASTM Standards, Part 6.

[2] The revised tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 6.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following two tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Methods of Test for:

Coefficient of Cubical Thermal Expansion of Plastics (D 864 - 45 T), and
Haze and Luminous Transmittance of Transparent Plastics (D 1003 - 49 T).

REAFFIRMATION OF STANDARDS

The committee recommends that the following seven standards, which have been published for 6 years or more without revision, be reaffirmed:

Tentative Methods of Test for:

Acetone Extraction of Phenolic Molded or Laminated Products (D 494 - 46),
Flammability of Plastics 0.050 in. and Under in Thickness (D 568 - 43),
Flammability of Plastics over 0.050 in. in Thickness (D 635 - 44),
Mar Resistance of Plastics (D 673 - 44),
Coefficient of Linear Thermal Expansion of Plastics (D 696 - 44), and
Shear Strength of Plastics (D 732 - 46).

Descriptive Nomenclature of:

Objects made from Plastics (D 675 - 45).

REPORT OF COMMITTEE D-21

ON

WAX POLISHES AND RELATED MATERIALS*

Committee D-21 on Wax Polishes and Related Materials met on June 11 and 12, 1952, in Boston, Mass. In addition, the subcommittees met at the National Bureau of Standards in Washington, D. C., on December 5 and 6, 1951. This December meeting was highlighted by an inspection trip of the National Bureau of Standards.

At the June meeting the following officers were elected for the two-year term 1952–1954:

Chairman, W. W. Walton.
Vice-Chairman, J. Vernon Steinle.
Secretary, B. S. Johnson.

During the year several new members were added to the committee which now consists of 52 members, of whom 21 are producers, 11 are consumers, and 20 are classified as general interest members.

The committee records with sorrow the death of Mr. E. H. Berger, of Johns-Manville Corp. Mr. Berger assisted in the establishment of Committee D-21, and his death is a great loss to the committee.

Numerous round-robin tests are in progress in the various subcommittees and it is expected that this work will lead to the early establishment of standards.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (Donald B. Hanley, chairman) is continuing its work on definitions and terminology.

Subcommittee II on Raw Materials (Melvin Fuld, chairman) has completed the first round-robin tests on methods of determining the moisture and dirt content of waxes. The information received has been used to set up a second series of round-robin tests which are now in progress. A method for determining the paraffin content of waxes by chromatography shows considerable promise and is being investigated further.

Subcommittee III on Chemical and Physical Properties (Donald M. King, chairman) has completed a round-robin test of a method for determining the non-volatile content of wax emulsions. The results are now being analyzed statistically to determine the accuracy of the method. Work is also progressing on methods for determining ash content and free alkali.

Subcommittee IV on Performance Testing (Michael Sveda, chairman).—The Section on Slip Resistance has completed a round-robin test designed to determine the reproducibility of results with the Sigler and Underwriters type slip testers. A further series of laboratory and field tests on the relative coefficient of friction of six different waxes is now in progress. The Section on Service Life is evaluating a method of measuring hardness of wax films using the Sward Hardness Rocker. In addition, methods of measuring water spot resistance are undergoing careful scrutiny. The Section on Appearance is still plagued with the problem of preparing uniform test films of waxes. Three methods of application are being investigated thoroughly and round-robin tests of one method are under way.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

Subcommittee V on Specifications (William Joy, chairman) is completing a survey of existing specifications for water emulsion waxes. Progress is also being made on the preparation of recommended practices for the preparation and waxing of floors.

This report has been submitted to letter ballot of the committee, which consists of 52 voting members; 37 members have returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. W. WALTON,
Chairman.

B. S. JOHNSON,
Secretary.

REPORT OF COMMITTEE E-1

ON

METHODS OF TESTING*

Committee E-1 on Methods of Testing held two meetings during the year at ASTM Headquarters in Philadelphia as follows: on January 3 and May 26, 1952.

During ASTM Committee Week in Cleveland, Ohio, on March 3 to March 7, 1952, meetings were held of ten E-1 subcommittees and task groups. Arrangements have been made for meetings of six subcommittees and seven task groups during the 1952 Annual Meeting of the Society.

During the year, the three Task Groups on Cupping Tests, Shear and Torsion Tests, and on Porous Filtering Bodies were established as permanent subcommittees.

New Task Groups are being organized on Thermocouples and Emf Instruments, under the chairmanship of E. J. Albert. Also a new Task Group on Bend Testing has been authorized under the chairmanship of K. M. McInerny. Consideration is being given to the subject of hydrostatic pressure testing.

Committee E-1 is sponsoring three symposiums at the 50th Anniversary Meeting of the Society in June. One will be devoted to the subject of Light Microscopy and will comprise eight technical papers. Arrangements for this symposium were made by a committee under the co-chairmanship of Mr. F. G. Foster, Bell Telephone Laboratories, Inc. and Mr. R. P. Loveland, Eastman Kodak Co. At the conclusion of the symposium and in the light of information to be presented, consideration will be given to the desirability of undertaking work on this subject in the Society, either under Committee E-1 or as a separate technical committee. The other two Symposiums on Determination of Elastic Constants, and on Conditioning and Weathering have been arranged under the sponsorship of Subcommittees 3 on Elastic Strength of Materials, and 14 on Conditioning and Weathering, respectively, as mentioned later in this report.

The Board of Directors has appointed Messrs. P. G. McVetty, Sam Tour, F. D. Tuemmler, and L. T. Work for another term of three years as members of Committee E-1.

The election of officers resulted in the selection of the following for the ensuing term of two years:

J. R. Townsend, chairman, and
R. L. Templin, vice-chairman.

Professor H. F. Moore was unanimously elected an Honorary Member of Committee E-1 in appreciation of his many contributions in the field of materials testing and his long and valued service to Committee E-1.

NEW STANDARD

The committee recommends for immediate publication as standard of the Hardness Conversion Table for Nickel and High-Nickel Alloys, as appended hereto.[1] The necessary nine-tenths affirmative vote at the Annual Meeting is requested in order that this recommendation may be referred to Society letter ballot. This conversion table has been prepared after careful study by Subcommittee 6 on Indentation Hardness of available data on hardness of the various nickel and high-nickel alloys. It is the third in a series of hardness conversion tables and supplements the two present tables for cartridge brass (E 33 - 42) and for steel (E 48 - 47).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The new standard was accepted by the Society and appears in the 1952 Book of ASTM Standards, Part 2.

NEW TENTATIVE

The committee recommends for publication as tentative the Method for Diamond Pyramid Hardness of Metallic Materials, as appended hereto.[2] This new method was developed in cooperation with Subcommittee V on Micro-Hardness, of Committee E-4 on Metallography. It represents the results of two years cooperative work and thorough study of this test procedure. This new method will be a companion standard to existing methods for Brinell hardness (E 10 - 50 T) and Rockwell hardness (E 18 - 42).

REVISION OF TENTATIVE

The committee recommends the following revisions of the Tentative Methods of Tension Testing of Metallic Materials (**E 8 - 51 T**).[3]

Section 1.—Change the last phrase in this section on scope to read as follows by the addition of the italicized words: "... and procedures for the tension testing of metallic materials *in any form*."

Section 18.—Revise to include as the second sentence the requirement which now appears as Footnote 11: namely, "In no case shall the gage length be less than 1 in. for copper and copper alloys." This change is recommended since the footnote has frequently been overlooked.

Figure 10.—Substitute the accompanying Fig. 1 showing an improved squeezing jig for flattening the ends of full-size tension test specimens.

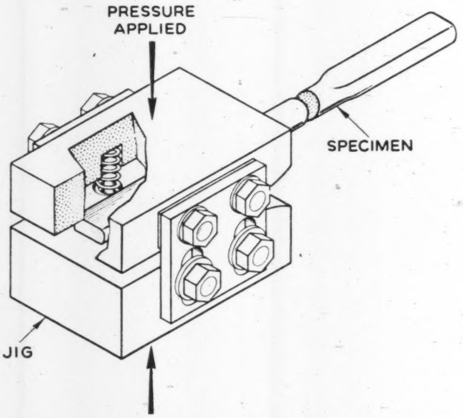

FIG. 1.—Squeezing Jig for Flattening Ends of Full-Size Tension Test Specimens.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Specifications for ASTM Thermometers (**E 1 - 51**[3a]) and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society:

Section 5.—Change to read as follows by the addition of the italicized word and figure: "5. The bulb shall be made of Corning normal, *Kimble R6* or equally suitable thermometric glass.

Section 6 (b).—Add the following: "*(4)* Precision Thermometers 65F, 66F, 67F, 67C, and 68C" to provide for terminal numbers, omitting this information from Table I for these thermometers.

Table I.—Revise the various thermometers in this table as follows:

On Thermometer 53 C, provide longer graduations at each "0.5 C" rather than at "1 C"; also graduations numbered at each "1 C" rather than at each "2 C".

For Kinematic Viscosity Thermometer 43 F, change the standardization test points to: "−60 F, −50 F, −40 F, −30 F, and + 32 F."

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[2] The new tentative was accepted by the Society and appears in the 1952 Book of ASTM Standards, Parts 1 and 2.

[3] 1951 Supplement to Book of ASTM Standards, Parts 1 and 2.

[3a] 1951 Supplement to Book of ASTM Standards, Part 5.

Revise the requirements for the Butadiene Boiling Point Thermometer 52C to that shown in the accompanying Table I.

Revise Aniline Point Thermometer 33 C to specify a distance of "112 to 124 mm" from bottom of bulb to graduation line at −35 C rather than "101 to 115 mm" to graduation line at −38 C. Also specify the distance of "32 to 51 mm" from top of thermometer to graduation line at 40 C rather than "25 to 45 mm" to graduation line at 42 C.

Add three new Aniline Point Thermometers 33 F, 34 F, and 35 F with Fahrenheit ranges corresponding to the Centigrade Thermometers 33 C, 34 C, and 35 C, respectively, as shown in the accompanying Table I.

Revise Flash Point Thermometers 9 C, 9 F, 10 C, 10 F, 57 C, and 57 F to specify length of enlargement as "2.5 to 5.0 mm" rather than "3.0 to 5.0 mm"; also that the diameter of the enlargement shall be "7.5 to 8.5 mm" rather than "7.5 to 8.0 mm." Also require use of the test gage shown in Fig. 2 for checking dimensions of enlargements.

Withdraw Tung Oil Thermometer 32 C, as this thermometer is no longer specified in the Methods of Testing Drying Oils (D 555 – 51 T).

In Saybolt Viscosity Thermometers 17 C to 22 C and 17 F to 22 F, specify the bottom of the enlargement to be "112 to 116 mm" above the bottom of the bulb rather than "114 mm."

Include the new Oil in Wax Thermometer shown in the accompanying Table I to replace Thermometer 55 F.

On Partial Immersion Thermometers 2 C and 3 C, change the temperature range to begin at "−5 C" rather than "−7 C."

On the Pensky-Martens and Tag Thermometer 9 C, begin the temperature range at "−5 C" rather than "−7 C", subject to approval by Committee D-2.

Revise the Loss on Heat Thermometer 13 C, to require marking at "0 C", "155 C," "163 C," and "170 C," with long lines at "5 C" and at "163 C," the lines at each 1 C being intermediate in length and the lines for each 0.5 C being the shortest.

On Partial Immersion Thermometer 1 F, the value of "−4 F" for the immersion column data is below the lowest thermometer range. Accordingly, change the thermometer reading from "−4 F" to "0 F" with emergent stem temperature of 48 F, the latter having been furnished by the National Bureau of Standards which supplied the present requirement.

On Kinematic Viscosity Thermometers 28 F to 30 F and 44 F to 48 F, change the total length from "240 to 245 mm" to "300 to 305 mm;" also change the distance from top of thermometer to upper graduation line from "27 to 47 mm" to "87 to 107 mm," subject to approval by Committee D-2.

Eliminate requirement for red ring on ASTM Open Flash Thermometers 11C and 11F.

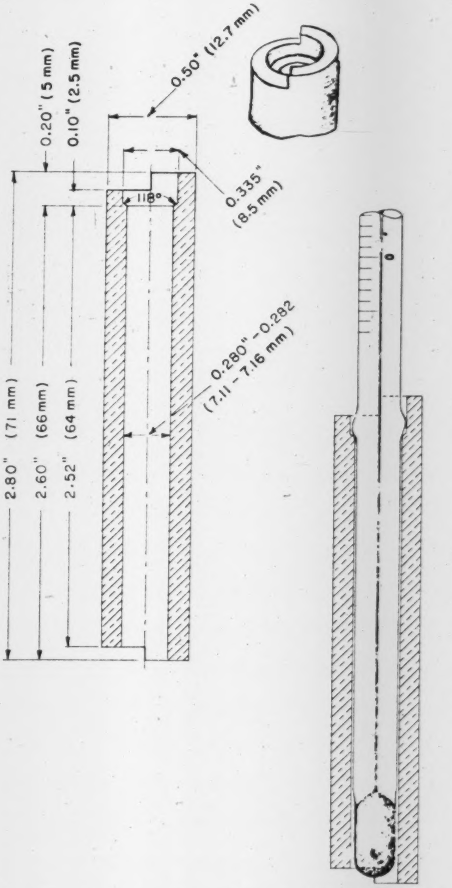

FIG. 2.—Test Gage for Checking Enlargements on Thermometers 9 C, 9 F, 10 C, 10 F, 57 C, and 57 F.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends for adoption as standard the following tentative specifications for thermometers published in Table I of the Standard Specifications for ASTM Thermometers (**E 1 – 51**):

Solvents Distillation Thermometers 37 C – 44 T to 42 C – 44 T, inclusive,

Stormer Viscosity Thermometer 49 C – 47 T,

Benzene Freezing Point Thermometer 53 C – 49 T,

Congealing Point Thermometer 54 F – 46 T,

TABLE I.—SPECIFICATIONS FOR ASTM THERMOMETERS.

NOTE.—Letter "T" in ASTM Thermometer Number indicates specifications for that thermometer are tentative.

Name	**ASTM Aniline Point**	**ASTM Aniline Point**	**ASTM Aniline Point**
ASTM Thermometer No.	33 F - 52 T	34 F - 52 T	35 F - 52 T
Immersion	2 in.	2 in.	2 in.
Temperature Range	−36.5 to 107.5 F.	77 to 221 F.	194 to 338 F.
Subdivisions	0.5 F.	0.5 F.	0.5 F.
Longer Grad. Lines at Each	1 F.	1 F.	1 F.
Graduations Numbered at Each Multiple of (Sec. 6 (*b*))	5 F.	5 F.	5 F.
Scale Error at any point when standardized shall not exceed	0.5 F.	0.5 F.	0.5 F.
Standardization	[a]	[a]	[a]
Total Length	403 to 409 mm.	403 to 409 mm.	403 to 409 mm.
Stem Diameter	6.0 to 7.0 mm.	6.0 to 7.0 mm.	6.0 to 7.0 mm.
Bulb Diameter	5.0 to 6.0 mm.	5.0 to 6.0 mm.	5.0 to 6.0 mm.
Bulb Length	10 to 20 mm.	10 to 20 mm.	10 to 20 mm.
Contraction Chamber:			
Bottom of bulb to top of chamber, max.	....	35 mm.	35 mm.
Position of mercury at 0 C.	....	near middle	near middle
Bottom of Bulb to Graduation Line at	−31 F.	77 F.	194 F.
Distance	101 to 115 mm.	112 to 114 mm.	101 to 115 mm.
Top of Thermometer to Graduation Line at	104 F.	221 F.	338 F.
Distance	25 to 45 mm.	32 to 51 mm.	25 to 45 mm.
Expansion Chamber shall permit heating to	212 F.	302 F.	428 F.
Top Finish	glass ring	glass ring	glass ring
Special Inscription on Thermometer (See Section 7)	ASTM ANILINE PT 2 IN IMM	ASTM ANILINE PT 2 IN IMM	ASTM ANILINE PT 2 IN IMM

[a] The aniline point thermometers shall be standardized for 2-in. immersion and for the following temperatures of the emergent mercury column:

−36.5 to 107.5 F. Thermometer		77 to 221 F. Thermometer		194 to 338 F. Thermometer	
Standardization Temperature	Average Temperature of Emergent Mercury Column	Standardization Temperature	Average Temperature of Emergent Mercury Column	Standardization Temperature	Average Temperature of Emergent Mercury Column
−31 F.	41 F.	77 F.	77 F.	212 F.	158 F.
−4 F.	59 F.	122 F.	104 F.	266 F.	140 F.
32 F.	68 F.	167 F.	113 F.	320 F.	122 F.
68 F.	77 F.	212 F.	113 F.		
104 F.	86 F.				

TABLE I.—SPECIFICATIONS FOR ASTM THERMOMETERS (*Concluded*).

NOTE.—Letter "T" in ASTM Thermometer Number indicates specifications for that thermometer are tentative.

Name	**ASTM Butadiene Boiling Point Range**	**ASTM Oil in Wax**
ASTM Thermometer No.	52 C - 52 T	71 F - 52 T
Immersion	total	3 in.
Temperature Range	−10 to −5 C.	−35 to +70 F.
Subdivisions	0.1 C	1 F.
Longer Graduation Lines at Each	0.5 C.	5 F.
Graduations Numbered at Each Multiple of (See Section 6 (*b*))	1 C.	10 F.
Scale Error at any point when standardized shall not exceed	0.1 C.	0.5 F.
Standardization	Total Immersion	−30, 0, 32, 70 F., and average temperature of 70 F. of emergent mercury column for 3-in. immersion
Total Length	157 to 163 mm.	350 to 355 mm.
Stem Diameter	6.0 to 6.5 mm.	7.0 to 8.0 mm.
Bulb Diameter	5.5 mm. to not greater than stem	6.0 to 7.0 mm.
Bulb Length	9.0 to 13 mm.	15 to 20 mm.
Bottom of Bulb to Graduation Line at	−10 C.	−35 F.
Distance	28 to 36 mm.	170 to 185 mm.
Top of Thermometer to Graduation Line at	+5 C.	70 F.
Distance	35 to 51 mm.	45 to 60 mm.
Expansion Chamber shall permit heating to	100 C.[a]	220 F.
Top Finish	plain	plain
Special Inscription on Thermometer (See Section 7)	ASTM BUTA B P R	3 IN I MM ASTM OIL IN WAX

[a] Expansion chamber shall be of the long narrow type and there shall be not less than 10 mm. of unchanged capillary between the base of the chamber and the top graduation.

Tag Closed Tester, Low Range, Thermometers 57 C – 51 T and 57 F – 51 T,
Tank Low Thermometer 58 F – 48 T,
Tank Medium Thermometer 59 F – 48 T,
Tank High Thermometer 60 F – 51 T, and
Petrolatum Melting Point Thermometers 61 C – 49 T and 61 F – 49T.

AMERICAN STANDARDS

The committee recommends that the Society submit to the American Standards Association the following for approval as American Standards:

Standard Specifications for ASTM Thermometers (E 1 – 52),
Standard Hardness Conversion Table for Cartridge Brass (Relationship Between Diamond Pyramid Hardness, Rockwell Hardness, and Brinell Hardness) (E 33 – 42),
Standard Hardness Conversion Tables for Steel (Relationship Between Diamond Pyramid Hardness, Rockwell Hardness, and Brinnell Hardness) (E 48 – 47), and
Standard Hardness Conversion Table for Nickel and High-Nickel Alloys (E 93 – 52).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES AND TASK GROUPS

Subcommittee 1 on Calibration of Mechanical Testing Machines and Apparatus (B. L. Wilson, chairman).—Proposed revisions in Tentative Methods of Verification of Testing Machines (E 4 – 50 T), of Verification of Calibration Devices for Verifying Testing Machines (E 74 – 50 T), and of Verification and Classification of Extensometers (E 83 – 50 T) are under consideration. Task groups were appointed to prepare suggested revisions of parts of E 4 and E 74 and an appendix for E 83. These revisions will be submitted to the Society through the Administrative Committee on Standards later in the year.[5]

Subcommittee 2 on Effect of Speed in Mechanical Testing (P. G. McVetty, chairman).—Work has been continued on further revision of the speed requirements in the Methods of Tension Testing of Metallic Materials (E 8 – 51 T), including correlation with AISI and Federal specifications. The need for similar activity in the various fields of nonmetallic materials has been recognized, and the membership of the subcommittee has been enlarged to provide for work on this problem. A supplement to the Bibliographies on Speed of Testing, previously published, is in preparation to bring this material up to date. The review of new testing equipment continues to keep members informed concerning the latest developments in equipment for speed control and measurement.

Subcommittee 3 on Elastic Strength of Materials (F. M. Howell, chairman).—The work of this subcommittee has been carried on primarily by two very active task groups.

The *Task Group on Elastic Constants* under Walter Ramberg, chairman, made arrangements for the Symposium on the Determination of Elastic Constants,[6] at the 50th Anniversary Meeting in June which will include five technical papers.

The *Task Group on Correlation of Definitions Relating to Methods of Testing*, under the chairmanship of P. G. McVetty, has been endeavoring to correlate similar definitions in the Standard Definition of Terms Relating to Methods of Testing (E 6 – 36) and in the Appendix to the Tentative Method of Test for Tensile Properties of Plastics (D 638 – 49 T). So many difficulties were encountered that it was decided to publish in the ASTM BULLETIN, May 1952, p. 66, a list of definitions that Committee D-20 on Plastics has adopted for inclusion as an Appendix to Methods D 638. The wording of these definitions, while acceptable to Committee D-20, has been influenced by a desire to make them applicable to metallic as well as non-metallic materials. This has resulted in definitions not entirely satisfactory to either the "non-metallic" or the "metallic" interests. For this reason, along with the definitions in the BULLETIN there are printed statements regarding the suitability or otherwise of the definitions and a request for constructive criticism.[7] It is hoped that this will result in the committee receiving comments that will be helpful in writing definitions sufficiently specific as to meaning and yet having applicability to a broad range of materials.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[5] See Editorial Note, p. 526.

[6] Issued as separate publication *ASTM STP No. 129.*

Subcommittee 4 on Tension Testing (R. L. Templin, chairman).—The revisions in the Tentative Methods of Tension Testing of Metallic Materials (E 8 - 51 T) recommended earlier were prepared by a Task Group under the chairmanship of G. R. Gohn. The Task Group has completed its assignment and has been discharged with thanks.

The *Task Group on Bursting Strength of Thin Metallic Materials* under the chairmanship of R. H. Heyer, has reported that work is being done by one manufacturer toward the construction of a device for recording autographically and simultaneously the deformation and pressure during a Mullen test. Modifications in the design of this device are being made to improve its functioning. It is believed to be necessary to obtain a measure of deformation as well as pressure in order to distinguish between tempers of thin metallic foils.

Subcommittee 6 on Indentation Hardness (R. H. Heyer, chairman).—The Tentative Method of Test for Diamond Pyramid Hardness of Metallic Materials, submitted herewith was drafted by a joint Task Group of this Subcommittee and E-4 Subcommittee V members. Also recommended to Committee E-1 after favorable letter ballot was the Standard Hardness Conversion Table for Nickel and High-Nickel Alloys.

The subcommittee has reviewed a proposed Tentative Recommended Practice for Brinell Hardness Test of Cast Iron and made recommendations for modifications to Committee A-3 on Cast Iron. The subcommittee also reviewed a proposed Tentative Method of Test for Hardness of Electrical Contact Material and made recommendations for modifications to Committee B-4 on Electrical Heating, Resistance, and Related Alloys.

Revisions of the Tentative Method of Test for Brinell Hardness of Metallic Materials (E 10 - 50 T) and the Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 - 42) are under study.

Task groups are also at work on test methods for rapid, direct-reading types of hardness testers using the Brinell indenter, and on test methods for portable hardness testers.

Subcommittee 8 on Flexure Testing (H. F. Clemmer, chairman) has prepared a proposed Tentative Method for Making Three-Edge-Bearing Test of Pipe. This method of test covers procedures for making the three-edge-bearing test of circular pipe and drain tile of concrete or clay, and cast-iron culvert pipe. Consideration of some editorial changes in this method is now under way.

Subcommittee 9 on Rheological Properties (W. F. Fair, Jr., chairman).—This subcommittee finished last year the comprehensive Report on the Principles Involved in the Determination of Absolute Viscosity.[8] It is understood that this report is being made available in reprint form as there has been considerable interest in this project.

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[7] See ASTM BULLETIN, May, 1952, p. 66; October, 1952, p. 25; January, 1953, p. 41.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 441 (1951).

The *Task Group on Absolute Viscosity* has considered a request from the American Standards Association to serve as the nucleus of an American group to advise on rheological matters in connection with Technical Committee 66 on Viscosity, of the International Organization for Standardization. The Task Group on Viscosity is willing to accept such responsibility.

The *Task Group on Rheology Definitions*, under R. N. Traxler, chairman, has under review revision of the Standard Definition of Terms Relating to Rheological Properties of Matter (E 24 – 42). It is planned to further consider these revised definitions at a meeting of the task group in June.

The *Task Group on Furol Viscosity of Asphalts at High Temperatures* under R. R. Thurston, chairman, has conducted a further series of cooperative tests during the past year, but has found that one or two cooperators' results are not in line with the balance. These cooperators are rechecking their work and the group hopes to have the method ready for recommendation to Committee E-1 during the year.

The *Task Group on Softening Point* under W. A. Kirklin, chairman, composed of representatives of eight interested technical committees, currently is charged with reconciling the differences between Ball-and-Ring Softening Point Methods D 36 – 26 and E 28 – 51 T, with the objective of combining them into one standard. Last year a proposed revision of Method E 28, embodying the agreements reached to date, was approved and published. Recommendations on design and simplification of the required apparatus has been requested from E-1 Subcommittee 21 on Metalware Laboratory Apparatus, to facilitate procurement of the equipment. Committee D-4 on Road and Paving Materials is the sponsor of Method D 36 – 26, and its Subcommittee B-5 on Softening Point is actively studying instructions for preparation of tar and asphalt samples, as well as other details of Method E 28 – 51 T. Subcommittee XI on Resins, of Committee D-1, is awaiting recommendations of Subcommittee 21 before approaching different laboratory equipment houses for the necessary apparatus and proceeding with additional cooperative test work.

Subcommittee 11 on Subsieve Testing (L. T. Work, chairman).—The Task Group on Subsieve Testing by the Optical Microscope under R. P. Loveland, chairman, has under review the Tentative Recommended Practice for Analysis by Microscopical Methods for Particle Size Distribution of Particulate Substances of Subsieve Sizes (E 20 – 51 T). This subject will be considered by Mr. Loveland in his paper in the Symposium on Light Microscopy.[9] Consideration is also being given to the dark-field count method.

An investigation of some of the standards and limits of accuracy in particle size determination by the light microscope has been under way for some time in the Kodak Research Laboratories. Part of this project has been a cooperative effort among some of the members of this task group. One phase of this project is complete, that is, the effect of optical and photographic factors on apparent size. Some of the results of this investigation will be discussed also in the Symposium.

Subcommittee 12 on Methods for Density (Wilmer Souder, chairman).—This subcommittee reviewed the following methods of testing and suggested changes for consideration by the originating committees: Tests for Specific Gravity of Road Oils, Road Tars, Asphalt Cements and Soft Tar Pitches, prepared by Committee D-4 on Road and Paving Materials, and Test for Density of Preformed Block and Preformed Pipe Types of Thermal Insulation, prepared by Committee C-16 on Thermal Insulating Materials.

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[9] Issued as separate publication *ASTM STP No. 143.*

Subcommittee 14 on Conditioning and Weathering (A. C. Webber, chairman).—Arrangements for the Symposium on Conditioning and Weathering[10] to be held at the Annual Meeting were made by a special committee under the chairmanship of R. Burns. The Symposium includes 10 papers which deal with new apparatus and techniques and a review of applications to a representative group of materials.

Information on humidity cabinet tests has been obtained preparatory to organizing a task group to undertake this project.

Subcommittee 15 on Chemical Analysis (J. W. Stillman, chairman).—Several important matters have been discussed by this subcommittee but action has been delayed until further consideration could be given to them. The question of the need for the publication in a separate volume or volumes of the ASTM Methods for the Chemical Analysis of Non-metallic Materials has been discussed. There is a feeling that such separate publication would prove useful as it has in the case of the Book on ASTM Methods for Chemical Analysis of Metals.

Subcommittee 15 feels that general recommendations on form of chemical methods should be prepared for general use by all committees and it proposes to prepare a draft of such recommendations.

In the face of a demand for so-called "routine" methods to supplement the "referee" type of method which is used by ASTM committees for specification purposes, discussion in Subcommittee 15 indicates that the preparation of methods suitable for day-to-day laboratory use should be encouraged after the "referee" method has been issued.

Subcommittee 15 recommends that whenever possible a statement of the precision attainable should be included in each chemical method prepared.

Subcommittee 16 on Thickness Measurement (K. G. Coutlee, chairman).—The work of this subcommittee has been reactivated and consideration given to a program of work to be undertaken. The subcommittee considered a problem presented by representatives of Committee B-4 regarding the calibration of micrometers for thickness measurement of electronic tube elements.

The Standards Methods of Test for Thickness of Solid Electrical Insulation (D 374 – 42), prepared by Committee D-9, have been transferred to the jurisdiction of this subcommittee, as this method is being quite widely used for thickness measurement of materials other than electrical insulation. Some changes in the method already under discussion in Committee D-9 will be reviewed and appropriate steps taken for revision of the method.

The subcommittee has under review the summary of information on "Measurement of Thickness of Textiles and Similar Materials"[11] by W. E. Emley, former chairman of this subcommittee.

Subcommittee 17 on Thermometers (R. M. Wilhelm, chairman).—Several requests from other technical committees, particularly Committee D-2 on Petroleum Products and Lubricants, concerning new specifications and changes in existing thermometer specifications have been considered. The subcommittee has also given further consideration to additional improvements and elimination of inconsistencies in manufacturing details of the established thermometer specifications. This has resulted in recommendations covering changes and additions to the Standard Specifications for ASTM Thermometers (E 1 – 51), given earlier in this report.

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[10] Issued as separate publication *ASTM STP No. 133.*

[11] *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part I, p. 608 (1931).

Revisions in the Tentative Methods of Testing and Standardization of Etched-Stem Liquid-in-Glass Thermometers (E 77 – 49 T) will be submitted to the Society during the summer.[5]

The subcommittee has considered the need for making available at an early date to those interested information concerning new thermometer specifications and changes in existing specifications. This will be accomplished through periodic articles in the ASTM BULLETIN listing the actions taken. Those interested in obtaining complete information concerning the contemplated recommendations can obtain a copy on request to ASTM Headquarters. Complete details will be furnished in response to such requests, and each correspondent will be subsequently advised when the particular revisions are adopted by the Society. It is also proposed that contemplated actions on thermometers should be further publicized in the *News Bulletin* of the Scientific Apparatus Manufacturers Association.

Subcommittee 18 on Hydrometers (R. D. Thompson, chairman).—Mr. J. P. Bader, who had been chairman of the subcommittee for many years, has been forced to resign as chairman in view of the pressure of business activity. R. D. Thompson has been appointed as chairman. Mr. J. J. Moran has been designated to serve as the secretary of the subcommittee.

There have been a number of personnel changes, including additional representatives from other technical committees.

A Task Group under the chairmanship of J. J. Moran completed the Proposed Specifications for ASTM Hydrometers[12] which includes requirements for 10 plain long-form A.P.I. hydrometers and 20 plain short-form A.P.I. hydrometers.

The subcommittee has decided to prepare methods of testing hydrometers comparable to the Tentative Method of Testing and Standardization of Etched-Stem Liquid-in-Glass Thermometers (E 77 – 49 T). A task group has been appointed to carry out this assignment.

Cooperative work is being carried on with the National Bureau of Standards leading toward a revision of the tolerances for certification of hydrometers which should be to the advantage of all interested groups.

Subcommittee 19 on Glassware Laboratory Apparatus (J. J. Moran, chairman).—Various members of this subcommittee have worked actively with the other committees of the Society on problems involving the standardization of specifications for glass apparatus used in ASTM methods, particularly with Committees D-2 on Petroleum, D-4 on Road Materials, and D-18 on Soils.

Subcommittee 21 on Metalware Laboratory Apparatus (E. L. Ruh, chairman).—The *Task Group on Laboratory Ovens* under the chairmanship of R. D. Stiehler, has prepared specifications for the critical requirements for cell type laboratory ovens with controlled rates of ventilation. Further consideration is being given to some editorial changes, after which it is planned to submit the specifications for publication as tentative.[5]

Through cooperative effort with other working groups in the Society, improvement in the following type of laboratory metalware apparatus has been achieved: (1) flash point test, (2) grease penetrometer cone, (3) distillation, (4) water determination, and (5) softening point. In each instance, the proposals have been accepted or are being considered.

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[12] See p. 527.

Subcommittee 22 on Hydrogen Ion Determinations (E. B. Ashcraft, chairman).—A considerable amount of work has been done towards the revision of the Tentative Method for Determination of the pH of Aqueous Solutions with the Glass Electrode (E 70 - 46 T).[5]

The first draft of a Proposed Tentative Method for the Colorimetric Determination of the pH of Aqueous Solutions is being prepared.

Subcommittee 24 on Cupping Tests (E. F. Lundeen, chairman).—At the organization meeting of this subcommittee on March 4, in Cleveland, Ohio, it was agreed the scope of activity should include workability, drawability, and formability of various types of sheet metals. It was decided to first make a survey of the workability of sheet metals. Abstracts published by the AISI will be reviewed. The following sheet materials will be included in this study: aluminum-base alloys, copper-base alloys, nickel-base alloys, magnesium-base alloys, steel, and zinc.

Subcommittee 25 on Shear and Torsion Tests (F. S. Mapes, chairman).—At its first meeting as a task group, it was agreed that some need for shear and torsion test methods exists in the fields not only of metals but in ceramics, plastics, rubber, wood, concrete, soils, sandwich materials, and the like. It was decided to first prepare a list of definitions and nomenclature, and to compile a bibliography. A questionnaire will be circulated to obtain information on these two subjects and also to determine what problems should be given first consideration. There is a definite need for stress-strain information on materials under shear or torsion stresses. There is also need to correlate shear and torsion properties with other physical properties of various materials. It thus appears that there is a very fertile field in which this task force can work with the hope eventually to arrive at general recommendations for conducting shear and torsion tests.

Subcommittee 26 on Filtration Materials (T. L. King, chairman).—This subcommittee (formerly Task Group D on Porous Filtering Bodies) is actively pursuing the project of developing a standard terminology for specifying the prime utility characteristics of filtering apparatus in common laboratory use. These characteristics are considered to be retentiveness (the ability of the filter to retain fine particles), and permeability (related to the rate of flow of fluids through the filter). Methods for measurement of these characteristics and a framework for their expression are in an advanced stage of development. It is hoped that the project can be completed during the current calendar year.

Plans are being formulated for the expansion of the subcommittee to include skills and experience commensurate with the responsibilities of the recently assigned broader scope of standards for filtration materials generally.

Task Group B on Low-Temperature Testing of Elastomers and Plastics (R. S. Havenhill, chairman) has prepared definitions of the most important low-temperature properties of rubber as shown by a survey, as follows: (1) Stiffness, (2) Brittleness, (3) Hardness, and (4) Rheological Properties.

In view of the results of the survey of low-temperature test methods in industry which indicated stiffness methods to be of most importance, a round-robin has been started on stiffness tests. Plans are under way for a round-robin on hardness tests.

A subgroup has been organized to make recommendations for low-temperature tests, for Technical Committee 45 on Rubber of the International Organization for Standardization.

A subgroup has also been appointed to correlate the Bureau of Ships low-temperature data and tests for specification work.

Task Group C on Water Vapor Permeability (Robert Burns, chairman).—A revision of the Proposed Method for Measuring Water Vapor Transmission, dated March 28, 1952, has been sent to the chairman of the interested technical committees for final comments. The proposed method incorporates, so far as feasible, the many excellent suggestions made by the various committees subsequent to circulation of the previous revision. Although the members of Task Group C had approved the earlier edition by letter ballot, it was felt that the comments accompanying the votes should be incorporated in a newer version which is now under consideration by the various interested committees, particularly C-16 on Thermal, Insulating Materials, C-17 on Asbestos-Cement Products, D-1 on Paint, Varnish, Lacquer, and Related Products, D-6 on Paper and Paper Products, D-9 on Electrical Insulating Materials, D-10 on Shipping Containers, D-14 on Adhesives, and D-20 on Plastics. It is hoped that the method can be submitted to letter ballot of Committee E-1 before the end of this year.

This report has been submitted to letter ballot of the committee, which consists of 12 members; 12 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

P. J. SMITH,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Cell Type Oven with Controlled Rates of Ventilation (E 95 – 52 T).

Revision of Tentative Method of:

Testing and Standardization of Etched-Stem Liquid-in-Glass Thermometers (E 77 – 49 T).

These recommendations were accepted by the Standards Committee on September 5, 1952. The new Tentative Specifications E 95 appear in Part 6 of the 1952 Book of ASTM Standards, and revised Methods E 77 appear in Part 5 of the Book of Standards.

On October 23, 1952, the Administrative Committee on Standards accepted the following recommendations submitted by Committee E-1:

Revision of Tentative Method for:

Determination of the pH of Aqueous Solutions with the Glass Electrode (E 70 – 46 T), and
Compression Testing of Metallic Materials (E 9 – 51 T).

Withdrawal of Tentative Method of:

Compression Testing of Metallic Materials in Sheet Form (E 78 – 51 T).

The revised Method E 70 appears in Parts 4, 5, 6 and 7 of the 1952 Book of ASTM Standards, and revised Methods E 9 appear in Parts 1 and 2 of the Book of Standards.

On November 18, 1952, the Administrative Committee on Standards accepted the recommendation of Committee E-1 that the Tentative Method of Verification and Classification of Extensometers (E 83 – 50 T) be revised. The revised method appears in Parts 1, 2 and 6 of the 1952 Book of ASTM Standards.

APPENDIX

PROPOSED SPECIFICATIONS FOR ASTM HYDROMETERS[1]

These are proposed specifications and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. These specifications cover glass hydrometers graduated in systems required by the various tests in which their use is required.

Description of Terms

2. For the purpose of interpreting these specifications, the following descriptions apply:

(*a*) *Total Length* is the over-all length of the finished hydrometer.

(*b*) *Length of the Scale* is the length of the nominal range in the stem. Graduations extending above and below the nominal limits are not included in the scale length.

(*c*) *Top of the Hydrometer* is the top of the finished instrument.

Specifications

3. Individual hydrometers shall conform to the detailed specifications given in Table I and to the general requirements specified in Sections 4 to 14.

Type

4. (*a*) Hydrometers shall be of the constant-mass, variable-displacement type. Hydrometers shall be made of glass, except for the scale, ballasting material, and the thermometric liquid of thermohydrometers.

(*b*) The outer surface of stem and body shall be symmetrical about the vertical axis. There shall be no uneven or unnecessary thickening of the walls, and no abrupt changes or constrictions that would hinder thorough cleaning or tend to trap air bubbles when the instrument is immersed.

(*c*) The hydrometer shall always float with its axis vertical.

(*d*) The hydrometer shall be thoroughly dry on the inside when sealed. The top of the stem shall be neatly rounded without unnecessary thickening.

(*e*) The glass shall be smooth, transparent, and free of bubbles, striae, or other imperfections that might interfere with the use of the hydrometer. The glass shall adequately resist the reaction of chemical agents to which hydrometers may be exposed, and also shall have suitable thermal properties to permit its use over the range of temperatures to which it may be subjected. In general, glasses suitable for constructing the bulbs of thermometers are satisfactory for hydrometers.

Body

5. The preferred shapes for the bodies of hydrometers are shown in Figs. 1 and 2.

Ballast

6. (*a*) Material used for ballast shall be secured to the lower part of the body, and no loose material of any sort may

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[1] These proposed specifications are under the jurisdiction of ASTM Committee E-1 on Methods of Testing.

TABLE I.—PROPOSED SPECIFICATIONS FOR ASTM HYDROMETERS.

	API Gravity Hydrometers Long Plain Form		**API Gravity Hydrometers** Short Plain Form	
	Designation	Nominal API Gravity Range, deg	Designation	Nominal API Gravity Range, deg
	1H	−1 to 11	21H	0 to 6
	2H	9 to 21	22H	5 to 11
	3H	19 to 31	23H	10 to 16
	4H	29 to 41	24H	15 to 21
	5H	39 to 51	25H	20 to 26
	6H	49 to 61	26H	25 to 31
	7H	59 to 71	27H	30 to 36
	8H	69 to 81	28H	35 to 41
	9H	79 to 91	29H	40 to 46
	10H	89 to 101	30H	45 to 51
			31H	50 to 56
			32H	55 to 61
			33H	60 to 66
			34H	65 to 71
			35H	70 to 76
			36H	75 to 81
			37H	80 to 86
			38H	85 to 91
			39H	90 to 96
			40H	95 to 101
Liquids for which Hydrometers are Intended	Light liquids (except alcohols)—especially petroleum products		Light liquids (except alcohols)—especially petroleum products	
Standard Temperature	60 F		60 F	
Subdivisions	0.1° API		0.1° API	
Intermediate Lines at	0.5° API		0.5° API	
Main (numbered) lines at	1.0° API		1.0° API	
Scale Error at any Point not to Exceed	0.1° API		0.1° API	
Scale Length	125 to 145 mm		48 to 61 mm	
Total Length	300 to 335 mm		158 to 168 mm	
Body Diameter	18 to 25 mm		12 to 18 mm	
Stem Diameter	4.0 mm, min		2.5 mm, min	

	API **Gravity Thermo-Hydrometers** Long Form with Thermometer (Thermometer Scale in Body)		API **Gravity Thermo-Hydrometers** Long Form with Thermometer (Thermometer Scale in Stem)	
	Designation	Nominal API Gravity Range, deg	Designation	Nominal API Gravity Range, deg
	51H	−1 to 11	71H	−1 to 11
	52H	9 to 21	72H	9 to 21
	53H	19 to 31	73H	19 to 31
	54H	29 to 41	74H	29 to 41
	55H	39 to 51		
	56H	49 to 61		
	57H	59 to 71		
	58H	69 to 81		
	59H	79 to 91		
	60H	89 to 101		
Liquids for which Hydrometers are Intended	Light liquids (except alcohols)—especially petroleum products		Light liquids (except alcohols)—especially petroleum products	
HYDROMETER SCALE				
Standard Temperature	60 F		60 F	
Subdivisions	0.1° API		0.1° API	
Intermediate Lines at	0.5° API		0.5° API	
Main (numbered) Lines at	1.0° API		1.0° API	
Scale Error at any Point not to Exceed	0.1° API		0.1° API	
Scale Length	125 to 145 mm		125 to 145 mm	

TABLE I.—PROPOSED SPECIFICATIONS FOR ASTM HYDROMETERS (*Concluded*).

	THERMOMETER SCALE	
Range	51H and 52H .... 60 to 220 F 53H and 54H .... 30 to 180 F 55H to 60H .... 20 to 130 F	30 to 220 F
Immersion	Total	Tota
Subdivisions	2 F	2 F
Intermediate Lines at	10 F	10 F
Main (numbered) Lines at	20 F	20 F
Scale Error at any Point not to Exceed	1 F	1 F
Scale Length	80 to 110 mm	105 to 145 mm
Total Length	375 to 400 mm	375 to 400 mm
Body Diameter	18 to 25 mm	18 to 25 mm
Stem Diameter	4.0 mm, min	6.0 mm, min

	Soil Hydrometer		Soil Hydrometer	
	Designation	Normal Range	Designation	Normal Range
	151H	0.995 to 1.038 sp. gr.	152H	−5 to 60 per liter[a]
Liquids for which Hydrometers are Intended	Suspensions of Soils		Suspensions of Soils	
Standard Temperature	68 F		68 F	
Divisions	0.001 sp gr		1 g per liter	
Intermediate Lines at	0.005 sp gr		5 g per liter	
Main (numbered) Lines at	0.010 sp gr		10 g per liter	
Scale Error at any Point not to Exceed	0.001 sp gr		1 g per liter	
Scale Length	See Fig. 2		See Fig. 2	
Total Length	278 to 282 mm		278 to 282 mm	
Body Diameter	See Fig. 2		See Fig. 2	
Stem Diameter	See Fig. 2		See Fig. 2	

[a] The soil hydrometer scale graduated in grams per liter is copyrighted.

be inside a hydrometer. When a cement is used to hold the ballast securely in place, this cement shall not soften below 105 C (221 F).

(*b*) When mercury is used for weighting, it shall be placed in a small bulb below the main bulb of the hydrometer, and completely separated from the bulb by means of a glass partition or by sealing the small opening between bulbs with a suitable cement. Solid material, such as shot, also may be placed in a similar small bulb.

Stem

7. The stem shall be uniform in cross-section, with no perceptible irregularities. It shall extend above the top graduation at least 15 mm, and continue cylindrical below the lowest graduation for at least 3 mm.

Scale

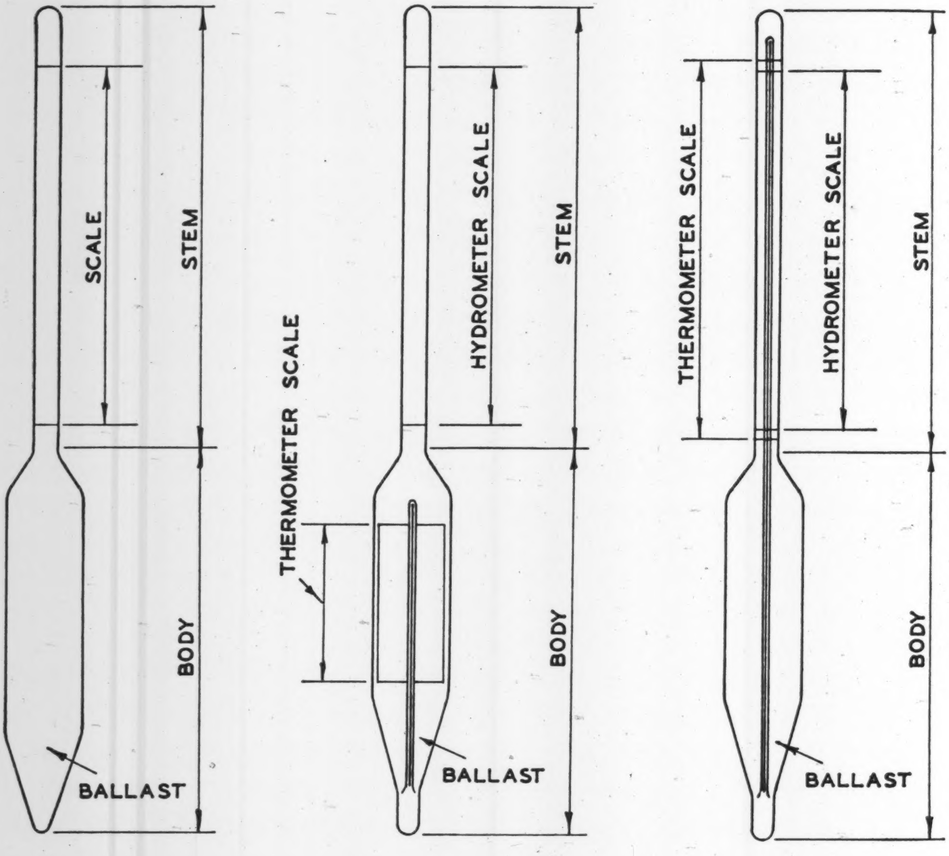
8. The material for the scale is optional. If paper is used, only No. 1 sulfite paper or ledger paper shall be used. The scale may be anchored by a design which prevents it from moving; otherwise it shall be fixed in place with a cement that will not soften below 105 C (221 F) and will not deteriorate with time. The paper shall show no evidence of scorching or charring when received, or after use at 105 C (221 F). The scale must be straight and without twist.

Graduations

9. (*a*) Graduation lines and inscriptions shall be in a permanent black marking material, such as India ink.

(*b*) All graduations shall be straight, fine lines not exceeding one fifth of the graduation interval in thickness, and in no case more than 0.2 mm. The lines shall be perpendicular to the vertical axis of the hydrometer. The lengths of main division lines, and the subdivision lines, shall be so chosen as to facilitate readings. The shortest lines shall be at least 2 mm long.

(*c*) All numbers for the API hydrometers must be complete. The numbers for 0.050 lines on specific gravity and density hydrometers must include the values for the first three decimal places, for example: 0.750, 0.900, 1.100; the other numbered lines may be abbreviated.


SCALE
STEM
BODY
BALLAST
THERMOMETER SCALE
HYDROMETER SCALE
STEM
BODY
BALLAST
THERMOMETER SCALE
HYDROMETER SCALE
STEM
BODY
BALLAST

(*a*) Plain Hydrometer.

(*b*) Thermo-Hydrometer with Thermometer in body

(*c*) Thermo-Hydrometer with Thermometer in Stem

FIG. 1.—API Gravity Hydrometers.

(*d*) For cemented scales, there shall be a permanent reference mark on the stem of the hydrometer corresponding to a designated reference mark on the scale.

Calibration

10. (*a*) All hydrometers shall be calibrated for reading correctly where the plane of the level liquid surface intersects the stem.

(*b*) Hydrometers indicating density shall be graduated to indicate, at the temperature marked on the scale, the density of liquids in grams per milliliter.

(*c*) Specific gravity hydrometers shall be graduated to indicate the ratio of the density of the liquid at a specified temperature to the density of water at a specified temperature.

(*d*) API hydrometers shall be graduated to give degrees of API gravity obtained as follows:

$$\text{API Gravity, deg} = \frac{141.5}{\text{sp gr } 60/60\,\text{F}} - 131.5$$

(*e*) Hydrometers shall be calibrated in the liquids specified in Table II, or in liquids having the same surface tensions at the temperature of standardization.

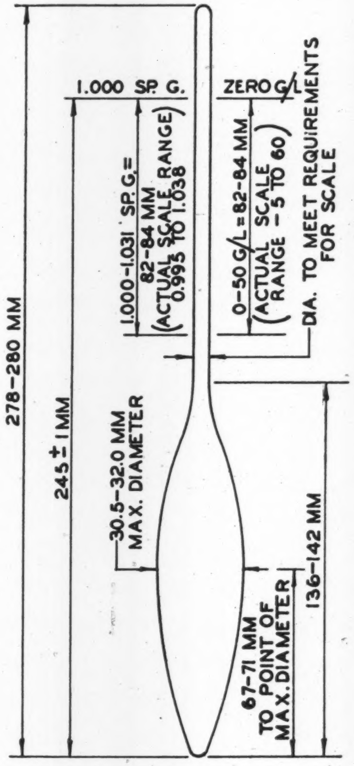

1.000 SP. G.
ZERO G/L
278–280 MM
245 ± 1 MM
1.000–1.031 SP. G.= 82–84 MM (ACTUAL SCALE RANGE 0.995 TO 1.038)
0–50 G/L = 82–84 MM (ACTUAL SCALE RANGE –5 TO 60)
DIA. TO MEET REQUIREMENTS FOR SCALE
30.5–32.0 MM MAX. DIAMETER
136–142 MM
67–71 MM TO POINT OF MAX. DIAMETER

FIG. 2.—Soil Hydrometers.

Thermo-Hydrometers

NOTE.—Although the thermo-hydrometer type of instrument is sufficiently satisfactory for routine use, the thermometer incorporated in it possesses certain inherent defects of design which render the thermo-hydrometer unfit for use in referee testing. Therefore, in all referee tests, the temperature of the sample being tested must be determined by means of a separate thermometer. Specifications for gravity thermometers are given in the Standard Specifications for ASTM Thermometers (ASTM Designations: E 1).[2]

11. (*a*) The capillary stem shall be essentially parallel to the hydrometer axis.

(*b*) When the thermometer scale is located in the stem of the hydrometer, the scale shall be in red to distinguish it from the hydrometer scale.

(*c*) When the thermometer scale is in the stem, calibration and testing of the thermometer shall be based on immersion of the thermometer scale to the level of the mercury in the thermometer stem (total immersion).

TABLE II.—LIQUIDS FOR CALIBRATING HYDROMETERS.

Density and Specific Gravity	API Gravity, deg	Liquid
HYDROMETERS FOR LIGHT LIQUIDS OTHER THAN ALCOHOL		
0.600 to 0.650	85 to 100..	Pentane
0.650 to 0.700	70 to 85..	Pentane and gasoline
0.700 to 1.100	−1 to 70..	Gasoline and sassafras oil (Synthetic)
HYDROMETERS FOR ALCOHOLS		
0.750 to 1.000	...	Ethanol and water
HYDROMETERS FOR HEAVY LIQUIDS		
1.000 to 1.830	...	Sulfuric acid-water mixtures
1.830 to 2.000	...	Thoulet solutions

(*d*) The requirements in Section 8 for the scale of the hydrometer shall apply also to the scale of the thermometer.

Special Inscription

12. (*a*) There shall appear on the scale or an extension thereof, or on a suitable label cemented permanently to the inside of the instrument, an inscription that indicates the purpose of the hydrometer. If necessary, this inscription should denote the liquid for which the hydrometer is intended, the temperature at which it is to be used, and the character of the indication.

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[2] 1951 Supplement to Book of ASTM Standards, Part 5.

(*b*) The designation of standard temperature and reference temperature may be abbreviated, for example, sp gr 60/60 F, means that the hydrometer indicates at 60 F the specific gravity of the liquid, referred to water at 60 F as unity.

(*c*) The inscription shall include also the hydrometer number (1H, 6H, etc.) but not the year designation (52, 53, etc.); a serial number; and the name or trademark of the manufacturer or vendor.

Standardization

13. When tests are made at three scale points, the points shall include at least 60 per cent of the graduated interval of the scale. Neither of the extreme points shall be farther from the nearest end of the graduated scale than a distance represented by 25 per cent of the length of the graduated scale. No two adjacent points shall be farther apart than a distance represented by 50 per cent of the length of the graduated scale.

NOTE.—When testing thermo-hydrometers, the thermometer in the instrument shall not be used to determine the temperature of the bath. An ASTM Gravity Thermometer as prescribed in ASTM Specifications E 1, or an instrument of equal sensitivity and accuracy, must be used.

Case

14. The hydrometer shall be supplied in a suitable carton on which shall appear the designation, name, and range, as given in Table I.

REPORT OF COMMITTEE E-2

ON

EMISSION SPECTROSCOPY*

Committee E-2 on Emission Spectroscopy held two meetings during the year, the first in Atlantic City, N. J., on June 21, 1951, and the second in Pittsburgh, Pa., on March 6, 1952. Meetings of the Advisory Committee were held in Atlantic City, N. J., on June 21, 1951, in Chicago, Ill., on October 23, 1951, and in Pittsburgh, Pa., on March 6, 1952.

The committee sponsored a Symposium on Chemical Analysis of Inorganic Solids by Means of the Mass Spectrometer at the 1951 annual meeting in Atlantic City. Three papers were presented as follows: "Mass Spectrometric Analysis of Solids with the High Frequency Spark," by J. A. Hipple; "Mass Spectrometric Analysis of Copper for Cuprous-Oxide Rectifiers," by W. M. Hickam; and "Isotopic Tracers as an Aid to Chemical Analyses with the Mass Spectrometer," by Mark G. Inghram. The papers are being prepared for publication as an ASTM technical publication.[1]

The committee has in preparation seven tentative methods, one of which, a revision of method E 27 – 43 T covering the Spectrochemical Analysis of Zinc-Base Alloys and Zinc, it is planned to submit for action of the Standards Committee. No formal action on standards is requested by the committee at this time.

Committee E-2 activities were carried out through its subcommittees and groups, all of which showed considerable activity during the year. The compilation of suggested analytical methods has progressed to final editing in the ASTM headquarters. Five new methods prepared this year will be included, making a total of 55 analytical methods and four suggested practices in this field. Publication of the compilation in book form is expected in 1953. An extension of the Index to the Literature on Spectrochemical Analysis to cover the period 1946 to 1950 is nearly completed and will be submitted soon for publication by the society.

The committee is pleased to record that its former chairman H. V. Churchill was honored with the ASTM Award of Merit at the 1951 Annual Meeting in Atlantic City.

The subcommittee organization remains unchanged except for the appointment of groups under several of the subcommittees to consider specific problems. These are discussed in the activities of the subcommittees as follows.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Apparatus and Equipment (R. W. Callon, chairman):

Group I, headed by R. G. Russell, has prepared a revised report on description and specification of spectrographic equipment (except source units). The first draft of a similar report on source units was prepared by C. H. Corliss and a report on power and voltage ratings of source units was prepared by H. M. Bedell. E. S. Hodge is preparing recommendations on describing equipment in analytical methods written by Committee E-2. The report of Group 2 on Suggested Practices for Installation and Safety in the Spectrochemical Laboratory, headed by G. A. Nahstoll, will be published in the forthcoming compilation of methods. Group 3 on Methods for Testing Spectrographic Equipment, R. W. Loofbourow, leader, has prepared a preliminary report. Group 4 on Quality of Photographic Materials, A. J. Mitteldorf, leader, is testing a new experimental emulsion, "Kodak Photoflure Film," and is investigating light sources for use in calibrating emulsions. Group 5, headed by T. M. Hess, has assembled data for a report on Spectrographic Accessories.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Issued as separate publication ASTM *STP No. 149.*

Subcommittee II on Fundamental Methods (R. W. Smith, chairman) is organized into seven groups. Group 1, headed by R. A. Wolfe, has completed its report on Specifications for Spark Generators and the report will be included in the forthcoming compilation. Group 2, headed by J. H. Coulliette, has prepared a report on calculations in the Mutual Standard Method. Group 3, headed by J. Sherman is continuing work on the evaluation of precision and accuracy in spectrochemical analysis. Group 4, leader C. Feldman, circulated within Committee E-2 its revised report on Photometric Practices. This report will be included in the forthcoming compilation. Group 5, headed by D. Fry, prepared a tentative semi-quantitative method which is being reviewed and tested within the group. Group 6, M. F. Hasler, leader, is reviewing its report on the Internal Standard Method. Group 7, H. A. Tuttle, leader, is completing a revision of its report on Photographic Processing, which is intended to be included in the compilation of methods.

Subcommittee III, Editorial (C. L. Guettel, chairman) has continued its arduous duties in the final revision of material for inclusion in the compilation of methods to be printed this year.

Subcommittee IV on Standards and Pure Materials (G. A. Nahstoll, chairman) has been organized into four groups as follows: Group 1, Ferrous Standards, D. J. Ward, leader; Group 2, Non-Ferrous Standards, Robert Raisig, leader; Non-Metallic Standards, R. H. Bell, leader; and Standard Forms for Graphite Electrodes, W. J. Edgar, leader. Each of these groups has begun its activities with a survey of needs for standards.

Subcommittee V on Copper, Nickel, and Their Alloys (E. K. Jaycox, chairman) has continued its review of suggested methods and is considering two methods for promulgation as tentative methods. The subcommittee has made preliminary analyses of a set of nickel samples; these samples are available to others for cooperative study.

Subcommittee VI on Lead, Tin, Antimony, Bismuth, and Their Alloys (E. J. Dunn, Jr., chairman) is considering methods for the sampling of tin alloys for spectrochemical analysis. Review and revision of suggested analytical methods were continued.

Subcommittee VII on Aluminum, Magnesium, and Their Alloys (J. R. Churchill, chairman) is completing reviews on additional suggested methods covering the analysis of aluminum alloys with a direct-reading spectrometer, the analysis of titanium alloys, the analysis of aluminum alloys by a pin electrode method, and the analysis of magnesium alloys by a pin electrode method. The subcommittee has prepared a proposed Tentative Method for Spectrochemical Analysis of Aluminum and Its Alloys by the Point-to-Plane Spark Technique, which it is planned to submit for action of the ASTM Standards Committee during the coming year.

Subcommittee VIII on Zinc, Cadmium, and Their Alloys (Alan Goldblatt, chairman) completed the revision of method E 27 - 43 T on the Spectrochemical Analysis of Zinc-Base Alloys and Zinc. A group under C. H. Aneshansley has completed a report on Sampling Procedures for Zinc and Zinc-Base Alloys. A tentative method for the analysis of zinc and zinc-base alloys using solid electrodes has been prepared and is undergoing review prior to submittal to Committee E-2.

Subcommittee IX on Ferrous Metals (P. R. Irish, chairman) has continued its preparation of a proposed tentative method on the analysis of ferrous alloys.

Subcommittee X on Non-Metals (R. G. Russell, chairman) is organized into several groups all of which are active and several methods are in preparation: Flame Photometry, E. S. Hodge; Agricultural and Biological Field, W. T. Mathis; Refractory Materials, George Oplinger; Non-Metallic Materials in the Iron and Steel Industry, W. J. Poehlman; Bureau of Mines Group, M. J. Peterson; and Atomic Energy Laboratories, H. R. Mullin.

A special Subcommittee on Sampling, headed by R. H. Bell, is engaging in preparing recommendations for sampling in spectrochemical analysis.

Plans are being made by a group under E. B. Ashcraft for a Symposium on Analysis by X-ray Fluorescence to be held at the 1953 annual meeting.

This report has been submitted to letter ballot of the committee, which consists of 120 members; 89 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

B. F. SCRIBNER,
Chairman.

J. H. COULLIETTE,
Secretary.

REPORT OF COMMITTEE E-3

ON

CHEMICAL ANALYSIS OF METALS*

Committee E-3 on Chemical Analysis of Metals held its main meeting at the Annual Meeting of the Society on June 20, 1951. Besides coordinating the activities of the divisions, plans were considered for the continual improvement of subsequent editions of the publication ASTM Methods of Chemical Analysis of Metals. The possibility of having newer releases in the form of loose-leaf pages is under consideration. By ballot a majority felt that such a plan would be worth while since, in this form, newer or revised methods could be continually added. Also under consideration is the publication by the committee of so-called routine methods, which at present is in contradiction to the committee's aim of providing only the best methods for handling particular elements and alloys. The question of how much one should deviate from the best precision and accuracy to design routine methods is under discussion.

The membership has lost through death in 1951 of Mr. C. Sterling, who had long been actively connected with the affairs of nickel and its alloys. In memoriam, a letter of condolence from the committee was sent to his immediate family.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Honorary Chairman, H. A. Bright.

Honorary Vice-Chairman, C. B. Francis.

Chairman, J. W. Stillman.

Vice-Chairman, Arba Thomas.

Secretary, H. Kirtchik.

Members of the Advisory Committee at Large, F. M. Barry and T. C. Bryson.

Adoption of Tentative as Standard

The committee recommends that the Tentative Methods for Chemical Analysis of Steel (E 30 - 50 T), covering procedures for boron, beryllium, and tin, be approved for reference to letter ballot of the Society for adoption as standard.

Editorial Change

The committee recommends the following editorial changes in the Standard Methods of Sampling Ferro-Alloys (E 32 – 42):[1] Delete the term "low-carbon" wherever it appears in the method for sampling ferrotitanium. Also, in the last paragraph of the method for sampling low-carbon ferrochromium, change the reference to a "420-micron (No. 40) sieve" to read "590-micron (No. 30) sieve."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Reaffirmation of Standards

The committee recommends reaffirmation of the following four standards, which have been published for six years without revision and are to be continued as such as no revisions are recommended at this time:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Book of ASTM Methods for Chemical Analysis of Metals.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Standard Methods of Chemical Analysis of:
Brasses (E 36 – 45),
Nickel (E 39 – 45),
Slab Zinc (E 40 – 45), and
Zinc-Brass Die-Casting Alloys (E 47 – 45).

CONTINUATION OF STANDARDS AND TENTATIVES WITHOUT REVISION

The committee recommends that all standards and tentatives under its jurisdiction, other than those previously mentioned in this report, be continued in their present status without change, pending further study.

ACTIVITIES OF SUBCOMMITTEES

Division F on Ferrous Metals (Arba Thomas, chairman).—At the June meeting of the division, reports of the progress of task groups covering methods for columbium and tantalum in stainless steels, aluminum in stainless steels, magnesium in cast iron, zirconium and manganese in steels, cobalt in high alloy steels, sulfur by combustion in steels and methods for the analysis of ferrotitanium and ferroboron were presented.

In the case of columbium and tantalum in stainless steels, two procedures have been studied by the group and, in general, the analytical data are quite satisfactory. The two methods are to be rewritten and modified somewhat with the hope of obtaining better performance.

The task group in charge of the development of a satisfactory method for aluminum in stainless steels has also studied several methods. The studies have been continued during the year with the hope that a satisfactory tentative method would be available by the time of the 1952 Annual Meeting.

Methods for the determination of magnesium in cast iron have also been studied, but it appears that a considerable amount of work is yet to be done before a method giving the desired accuracy and reproducibility will be forthcoming.

The task group in charge of developing a combustion sulfur method for plain steels and cast irons which will eliminate iron oxide fog and give a reproducible potassium iodate factor is still working on this project.

The zirconium task group has been active, but so far the procedures studied have not given the desired reproducibility and accuracy and further work will have to be done.

The work done so far on the development of a method for the determination of cobalt in high-alloy steels indicates that the potentiometric procedure may be satisfactory. Work on this method will continue in the coming year.

The study of the proposed methods for the analysis of ferrotungsten and ferrotitanium has reached a point where it is expected that by the 1952 Annual Meeting this task group will be able to make definite recommendations. The data obtained by the task force members using the proposed volumetric silicon method for the determination of this element in ferrotungsten were quite satisfactory. The National Bureau of Standards is preparing a standard ferroboron sample which will be used in the development of methods for the analysis of this ferroalloy.

The task group in charge of the work on a photometric method for manganese in chromium-vanadium, stainless, and similar steels, hopes to have a satisfactory procedure available by the 1952 Annual Meeting. However, additional work will have to be done in order to determine whether this procedure will be satisfactory for cobalt-bearing steels.

At the 1951 meeting of the Advisory Committee, authorization was obtained to proceed with the study of methods applicable to the analysis of high-silicon steels (electrical steels). A task group was formed. This group held a meeting on September 28, 1951, at the National Bureau of Standards and plans were laid for an active program on these steels.

Division G on General Analytical Methods (S. E. Q. Ashley, *chairman*):

Subcommittee G-1 on Reagents (T. C. Bryson, chairman) is in the process of resolving differences with D-19 on specifications for distilled water.

Subcommittee G-2 on Apparatus (T. L. King, chairman) has prepared specifications on a number of pieces of apparatus including the analytical balance, filter photometers, and electrolytic apparatus. A third draft of specifications on analytical balances was discussed and met with general approval.

Subcommittee G-3 on Common Procedures (M. D. Cooper, chairman) conducted a panel discussion of the methods of the determination of nickel which are in the 1950 edition of the Book of ASTM Methods for Chemical Analysis of Metals. As a result of the discussion it was concluded that a common procedure for nickel can be derived. Consequently, a proposed common procedure and an appropriately modified version of each individual method is being prepared by G-3 and will be submitted for consideration to the committee at the 1952 meeting. Although G-3 is awaiting the reactions of Divisions F and N to the above proposal before preparing similar studies of other methods, a tentative summary of the methods for the determination of phosphorus is being prepared.

Subcommittee G-4 on Precision and Accuracy (H. B. Lea, chairman) conducted an open forum discussion on the problems of precision and accuracy of analytical methods with which Committee E-3 is faced.

Division N on Non-Ferrous Metals (C. Zischkau, chairman)—Some discussion has been held on the possible reorganization of the division on a "task-group" basis, rather than in subcommittees. Action was deferred until a future meeting.

An informal symposium was held on the subject of the photometric determination of aluminum, and the interest was such as to indicate the desirability of making such symposia a regular feature of future meetings of the division.

Subcommittee N-1 on Copper and Its Alloys (R. P. Nevers, chairman) is proceeding with work on the drawing up of methods for the analysis of beryllium-copper alloys. During the year two additional methods for the determination of beryllium have been circulated, and it is expected that data will be available by the next Annual Meeting.

A special meeting was held at Barber, N. J., to consider methods for the analysis of fire-refined copper. To date, methods for arsenic and antimony have been tested and methods for selenium and tellurium will be circulated before the next meeting. The coming year should see the completon of this work, which would include the determination of lead and bismuth, in addition to the above mentioned elements.

Subcommittee N-2 on Lead, Tin, Antimony, Bismuth, and Their Alloys (C. L. Luke, chairman) has circularized methods for the determination of zinc and aluminum in lead, tin, and their alloys; test data is being accumulated.

A meeting was held at Woodbridge, N. J., to consider methods for the analysis of pig tin. A program of testing was outlined and distributed, along with a sample of high-purity tin which might be used as a matrix for testing the recommended procedures.

Subcommittee N-3 on Aluminum and Its Alloys (K. C. Braun, chairman) has under consideration the problem of improving the present method for the determination of zinc and the development of photometric methods for the determination of magnesium and silicon in aluminum alloys.

Subcommittee N-4 on Zinc and Its Alloys (R. K. Bell, chairman) reports that preliminary tests indicate that the photometric method for aluminum, using eriochromecyanin R, may be suitable for the determination of aluminum in spelter. Further work in progress by the subcommittee includes the determination of: low percentages of copper in zinc alloys by the cupric bromide photometric method, lead in zinc and zinc die-casting alloys by the dithizone photometric method, and magnesium in zinc die-casting alloys by a modification of the present diammonium phosphate method.

Subcommittee N-6 on Nickel and Its Alloys has continued the work on the analysis of electronic nickel by a task force under G. V. Potter. A proposed draft of methods for chemical analysis of electronic nickel is appended to the Report of Committee B-4 on Electrical Heating, Resistance, and Related Alloys[3] and will receive consideration in Committee E-3. Additional data are being collected on the analysis of several coöperative samples for cobalt, copper, manganese, iron, and titanium, and methods for the determination of silicon, aluminum, and magnesium are being tested.

Subcommittee N-9 on Magnesium and Its Alloys (V. A. Stenger, chairman) has been studying methods for the determination of zirconium and rare earth elements in preparation for their probable use as alloying agents for magnesium. The effect of these elements on the determination of other constituents is being considered. A photometric method for aluminum, applicable in the presence of zirconium and rare earths, has also been tested.

Proposed revisions in some of the present procedures in the Tentative Photometric Methods for Chemical Analysis of Magnesium and Magnesium-Base Alloys (E 35 – 50 T) are under consideration and will be submitted to letter ballot after study of test data is complete.

Division S on Sampling (J. P. Brull, chairman) has brought to the attention of the committee the fact that no method of sampling high-carbon ferrotitanium is included in the book of methods. An editorial change in the Standard Methods of Sampling Ferro-Alloys (E 32 – 42) is being submitted with this report which will cover this.

Subcommittee S-2 on Sampling of Non-Ferrous Alloys (A. C. Holler, chairman) has rewritten, revised, and submitted to the committee for study a method combining the Method of Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (E 55 – 48) and the Method of Sampling of Non-Ferrous Metals and Alloys in Cast Form for Determination of Chemical Composition (E 88 – 50 T). The subcommittee has also reviewed sampling methods for refined tin in pig form prepared by Committee B-2 on Non-Ferrous Metals and Alloys.

Division M on Miscellaneous Metals (R. M. Fowler, chairman *pro tem*) has commenced the assignment to task groups of the analysis of certain elements in titanium alloys.

This report has been submitted to letter ballot of the committee, which consists of 144 members; 71 members returned their ballots, of whom 70 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. STILLMAN,
Chairman.

H. KIRTCHIK,
Secretary.

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[3] See p. 159.

REPORT OF COMMITTEE E-4
ON
METALLOGRAPHY*

Committee E-4 on Metallography, together with several of its subcommittees, held meetings on March 3 and 4, 1952, during the committee week sessions of the Society in Cleveland, Ohio.

There have been several membership changes during the past year, leaving the committee with 96 members at this time.

It is with deep regret that Committee E-4 recognizes its great loss in the recent passing away of Dr. M. A. Grossman.

In addition to his sterling qualities as a man and as a scientist, the Society should be forever grateful to this man under whose guidance was established the universally recognized "Austenite Grain-Count" which has since proved to be the basis of all grain count methods.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. L. Wyman.
Vice-Chairman, R. E. Penrod.
Secretary, Mary Norton.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1951 Annual Meeting, Committee E-4 presented to the Society through the Administrative Committee on Standards a recommendation for the revision and reversion to tentative of the Recommended Practice for Thermal Analysis of Steel (E 14 – 33). This recommendation was accepted by the Standards Committee on July 10, 1951, and the new tentative appears in the 1951 Supplement to Book of ASTM Standards, Parts 1 and 2 under the new designation E 14 – 51 T, and the new title Tentative Recommended Practice for Thermal Analysis of Metals and Alloys.

The new Tentative Methods for Estimating the Average Grain Size of Non-Ferrous Metals, Other Than Copper, and Their Alloys (E 91 – 51 T) were accepted by the Standards Committee on August 21, 1951, and appear in the 1951 Supplement to Book of ASTM Standards, Part 2.

NEW TENTATIVES

While not having any new procedures of its own to recommend this year, the Tentative Method of Test for Diamond Pyramid Hardness of Metallic Materials currently being recommended through Committee E-1 is largely the product of the joint efforts of the task group representing Subcommittee V of E-4, together with Subcommittee VI of E-1.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods for Estimating the Average Ferrite Grain Size of Low-Carbon Steels (E 89 – 50 T)[1] be adopted as standard without change.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following two tentatives be continued as tentative without revision:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 1.

Tentative Methods of:

Preparation of Metallographic Specimens (E 3 – 46 T), and

Estimating the Average Grain Size of Wrought Copper and Copper-Base Alloys (E 79 – 49 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Activities of Subcommittees

Subcommittee I on Selection and Preparation of Samples (F. C. Hull, chairman) is currently revising Method E 3 in order to bring it up to date as well as to add methods for a number of new materials. Pending the completion of this work, the subcommittee has voted to continue Method E 3 – 46 T in its present status.

Subcommittee II on Definitions (R. S. Busk, chairman) has held several meetings in order to examine each one of the hundreds of definitions covering all E-4 activities. It is estimated that by the conclusion of the 1952 Annual Meeting this major task will be almost completed.

Subcommittee III on Nomenclature (P. A. Beck, chairman) has recently arrived at a suggested method of phase nomenclature which is presently being studied by a number of interested metallurgists. It is planned to have this system circulated widely for further suggestions before it is submitted as a specific proposal. The fact that a number of very favorable comments have already been received bespeaks well of this suggested solution to the old and perplexing problem of a uniform system of phase nomenclature for metallic systems.

Subcommittee IV on Preparation of Micrographs (S. W. Poole, chairman) has been actively engaged in the promotion of the photomicrographic exhibit for the current Anniversary Meeting. In addition to the fact that this is normally a big task, the extended program of aiming for student participation by cooperation with colleges and universities in order to revitalize interest in competent metallographic technique has necessitated an appreciable amount of added effort.

Subcommittee V on Micro-Hardness (Alexander Gobus, chairman) has been working with Subcommittee VI of Committee E-1 to produce the Proposed Tentative Method of Test for Diamond Pyramid Hardness of Metallic Materials. In addition to the above, this subcommittee is continuing its work on the optics and techniques for micro-hardness testing, relying upon many inter-laboratory tests.

Subcommittee VI on X-Ray Methods (W. L. Fink, chairman) is still concerned with a major revision of Recommended Practice E 43 – 49 T, the Hanawalt X-Ray Diffraction Method, in order that it may include the complete array of equipment and techniques used both here and abroad inasmuch as this method is so closely allied with the work of the Joint Committee on X-Ray Diffraction and its Card Index of Diffraction Data. Experimental work necessary to the proving out of the central portion of pole-figure work by the Shultz Method will permit the codification of this method. It is hoped to be able to do so within the next year.

Subcommittee VII on Methods of Thermal Analysis (D. I. Finch, chairman), having completely revised the thermal analysis methods (E 14 – 51 T) and reaffirmed the methods for dilatometric analysis (E 80 – 51 T), now proposes the establishment of recommended practices for temperature-resistance and temperature-emf methods of metallographic analysis.

Subcommittee VIII-B on Ferrite Grain Size (R. E. Penrod, chairman) is recommending that the Tentative Methods for Estimating the Average Ferrite Grain Size of Low-Carbon Steels E 89 – 50 T be adopted as standard without change.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee VIII-C on Non-Ferrous Grain Size (H. P. George, chairman) is recommending the continuance, without revision, of the Tentative Methods for Estimating the Grain Size of Wrought Copper and Copper-Base Alloys E 79 – 49 T.

With the adoption of E 91 – 51 T on non-ferrous grain size this past year, one may note that the array of grain size methods which Committee E-4 has established now encompass the entire metal field. In addition, attention may be called to the fact that these methods are mutually compatible, and provide a system of grain size determinative methods covering all present requirements. They also provide a continuity from macro to micrograin sizes and are not limited in either direction as to any future requirements for measuring either still larger or yet smaller sizes of grains.

Subcommittee X on Decarburization (J. J. B. Rutherford, chairman) is continuing its cooperation with the joint committee which includes SAE and AISI. There are no recommendations at this time at the present stage of the effort.

Subcommittee XI on Electron Microstructure of Steel (D. M. Teague, chairman) has completed the second phase of its work on the correlation of light and electron-microscope studies of the martensite-bainite reactions in eutectoid steel, these results being currently published with this report[3] as well as being presented to the Society during the Symposium on Electron Microscopy[4] which this subcommittee is sponsoring at the Annual Meeting of the Society. In addition to the above, this group is supervising the electron microscope section of the current photographic exhibit.

This report has been submitted to letter ballot of the committee, which consists of 96 members; 74 members returned their ballots, of whom 74 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. L. WYMAN,
Chairman.

MARY NORTON,
Secretary

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[3] See p. 543.

[4] The papers by Srube and Rouze, and Austin and Schwartz are appended to this report. The paper by Craig is found in this volume, see p. 878.

APPENDIX I

ELECTRON MICROSTRUCTURE OF BAINITE IN STEEL

(SECOND PROGRESS REPORT BY SUBCOMMITTEE XI OF COMMITTEE E-4)*

An earlier report by this Subcommittee on the "Electron Microstructure of Steel"[1] dealt with the results obtained from the examination of a series of microstructures in plain carbon eutectoid steel. After completing the examination of isothermal transformation products, as well as a series of quenched-and-tempered structures, several interesting observations were made.

One of these was the marked difference in structure that occurs upon isothermal transformation within the bainite range between the temperatures of 500 and 950 F, (shown cross-hatched in Fig. 1). Although a difference in appearance between lower bainite and upper bainite can be observed with a light microscope, the difference is much more pronounced when examined with the electron microscope.

In view of the importance of these structures, and since they are not adequately resolved by the light microscope, the committee chose, as the next phase of its work, to investigate the isothermal transformation products formed within the bainite range in more detail. It was proposed to establish the transition temperature between lower and upper bainite by examining specimens that had been completely transformed at 500, 550, 600, 650, 700, and 750 F. No higher temperatures were necessary since it had already been shown by the earlier work that lower bainite is not formed at 750 F.

It was also proposed to study partially transformed structures containing upper bainite. Such specimens would be helpful in studying the nature and mode of formation of upper bainite. Any additional information that could be obtained along these lines might shed some light on the mechanism of the transformation which takes place in this region.

EXPERIMENTAL WORK

Following the procedure adopted for the earlier work, several sets of identical specimens were prepared in the laboratory of the U. S. Steel Co. The specimens were cut from a sample of the same steel used in the initial work and which has the composition shown:

Carbon, per cent	0.87
Manganese, per cent	0.44
Silicon, per cent	0.17
Phosphorus, per cent	0.013
Sulfur, per cent	0.006
Nickel, per cent	0.39
Chromium, per cent	0.21

All specimens were austenitized 35 min at 1800 F. This treatment produced a No. 5 ASTM austenite grain size.[2] To prevent excessive decarburization the specimens were copper-plated prior to heat treatment, and austenitized in a reducing atmosphere. The particular heat treatment given each specimen after austenitizing is shown in Table I. The specimens examined in the earlier work, which fall within or encompass the bainite range, are also included for completeness.

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* Members of Subcommittee XI actively participating in this study: D. M. Teague, *Chairman*—Chrysler Corp. Detroit, Mich. L. R. Cooper, *Secretary*—Heppenstall Co., Pittsburgh, Pa. L. A. Aldinger, General Motors Corp., Detroit, Mich. L. S. Birks, Naval Research Laboratory, Washington, D. C. E. J. Dofter, Chrysler Corp., Detroit, Mich. A. L. Ellis, International Harvester Co., Chicago, Ill. R. M. Fisher, United States Steel Co., Research Laboratory, Kearny, N. J. E. F. Fullam, General Electric Co., Knolls Research Laboratory, Schenectady, N. Y. W. L. Grube, General Motors Corp., Detroit, Mich. J. M. Hodge, United States Steel Co., Pittsburgh, Pa. D. M. McCutcheon, Ford Motor Co., Dearborn, Mich. H. C. O'Brien, Jr., Heppenstall Co., Pittsburgh, Pa. T. G. Rochow, American Cyanamid Co., Stamford, Conn. G. E Pellissier, United States Steel Co., Pittsburgh, Pa. E. S Rowland, Timken Roller Bearing Co., Canton, Ohio C. M. Schwartz, Battelle Memorial Institute, Columbus, Ohio J. R. Vilella, United States Steel Co., Research Laboratory, Kearny, N. J.

[1] "Electron Microstructure of Steel. First Progress Report of Subcommittee XI, ASTM Committee E-4 on Metallography," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 444 (1950).

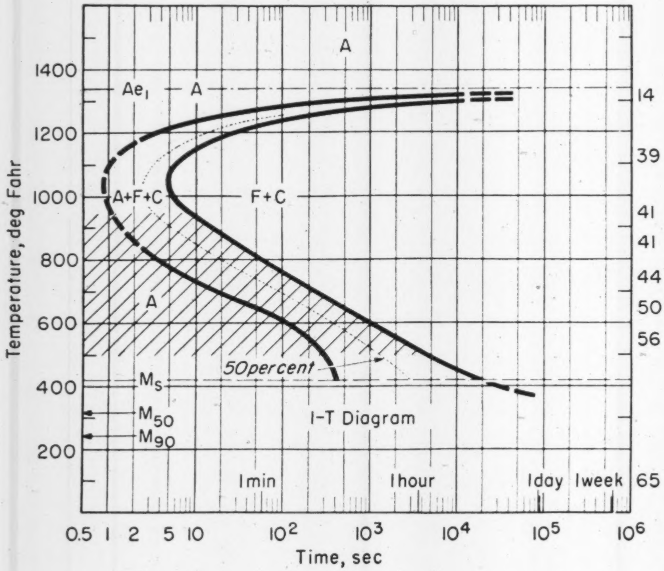

FIG. 1.—Isothermal Transformation Diagram of an Eutectoid Steel (U. S. Steel Co.).

Those specimens which were transformed at temperatures above 550 F, were quenched from the austenitizing temperature first into a bath at 550 F. This was done to increase the cooling rate through the intermediate temperature range where the delay in onset of transformation is shortest, and thus to prevent transformation during cooling. The holding time at this temperature was sufficiently short so that it is assumed that no significant transformation occurred. After 6 sec at 550 F the specimens were transferred to another bath at the desired temperature where they were held for a time sufficient to produce the desired amount of transformation.

Samples Nos. 17, 18, and 19 represent transformations of 20, 50 and 100 per cent, respectively. The transformation temperature selected for these partially transformed structures containing upper bainite was 850 F, since the needles of upper bainite formed in this region are relatively large and well-defined. At the

TABLE I.—HEAT TREATMENTS TO FORM BAINITE STRUCTURES.

Sample	Heat Treatment	Hardness Rockwell C Scale
No. 5	2⅓ hr at 500 F	57.4
No. 13	1 hr at 550 F	56.3
No. 14	6 sec at 550 F, 30 min at 600 F	53.2
No. 15	6 sec at 550 F, 15 min at 650 F	50.4
No. 16	6 sec at 550 F, 9 min at 700 F	47.2
No. 4	6 sec at 550 F, 7 min at 750 F	43.8
No. 17	6 sec at 550 F, 12 sec at 850 F	54.3
No. 18	6 sec at 550 F, 20 sec at 850 F	42.3
No. 19	6 sec at 550 F, 2 min at 850 F	40.6
No. 3	6 sec at 550 F, 1 min at 950 F	41.0

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[2] Standard Classification of Austenite Grain Size in Steels (E 19 - 46), 1949 Book of ASTM Standards, Part 1.

same time, this temperature is low enough so that little fine pearlite is formed.

The metallographic technique employed in the preparation of these specimens was:[3]

Polish—Mechanical, using customary procedure.

Etch—4 per cent picral.

Replica—Formvar or collodion negative, by direct stripping; metal shadowcast at 27 to 45 deg.

Print—Direct enlargement of micrograph negative.

Of the common etchants, picral was selected because it was found by experience to be the most satisfactory for developing uniformly the extremely fine structure found in lower bainite. The time of etching (etch depth) used depended upon the particular microstructure being examined. At least two etching times were used for each specimen in order to study the effect of etch depth on the appearance of the microstructure. The characteristics of other etchants, and their relationship to various microstructures in steel, will be discussed in detail in a forthcoming report on techniques.

DISCUSSION

Near the lower end of the bainite temperature range of 500 F (Fig. 1) the microstructure formed upon isothermal transformation, when examined under the light microscope at 2500 ×, appears as an acicular structure consisting of mottled needles of varying shades of gray (Fig. 2). The detail within these needles however, is much too small to be resolved by the light microscope, or even with the electron microscope at 2500 X (Fig. 3). Examination of this structure under the electron microscope at higher magnifications reveals that the ultimate microstructure of lower bainite is characterized by ferrite needles containing many small carbide platelets in parallel array (Fig. 4). Within each needle these parallel platelets are oriented at an angle of approximately 55 degrees with respect to the needle axis. The apparent differences in size between these platelets is largely a reflection of differences in orientation of the needles with respect to the plane of polishing.

Preliminary electron diffraction measurements[4] made on bainite transformed at 500 F indicate that the slow-etching constituents are principally cementite, Fe_3C, although some hexagonal ϵ-iron carbide[5, 6] is present.

When the transformation takes place isothermally at 550 F the resulting structure appears under the light microscope at 2500 × as shown in Fig 5. It will be noted that the gross appearance is very similar to that of 500 F bainite. The similarity persists when the fine structure is examined under the electron microscope at 15,000 ×. Like that formed at 500 F, the structure consists of ferrite needles which contain extremely minute carbide platelets arranged in a parallel array at an angle to the needle axis (Fig. 6). The electron micrograph also shows that these particles, as in the lower temperature structure, are plate-like in shape and that most of the apparent difference in size is due to differences in orientation of the plates with respect to the surface being examined.

Preliminary electron diffraction measurements on the slow-etching microconstituents of the bainite specimens transformed at 550 F and at higher temperature did not detect the presence of hexagonal ϵ-iron carbide. Only the diffraction lines corresponding to cementite were observed. The cross-striated needle structure characteristic of lower bainite persists in the specimens transformed at 550 and 600 F and hence it might be assumed that the platelets in these specimens are cementite. Additional measurements will be made to confirm this point.

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[3] For a more complete description see the Appendix of "Electron Microstructure of Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 489 (1950).

[4] Courtesy of Battelle Memorial Institute.

[5] K. H. Jack, "Results of Further X-Ray Structural Investigation of Iron-Carbon and Iron-Nitrogen Systems and of Related Interstitial Alloys," *Acta Cryst.*, Vol. 3, p. 392 (1950).

[6] K. H. Jack, "Structural Transformations in the Tempering of High-Carbon Martensitic Steels," *Journal*, Iron and Steel Inst. Vol. 169, p. 26 (1951).

Upon transformation at 600 F a microstructure as shown in Fig. 7 is obtained. The microstructure of this specimen under the light microscope strongly resembles that obtained at 550 F, and under the electron microscope at 15,000 × the characteristic fine structure of lower bainite still prevails (Fig. 8).

When transformation is allowed to take place at 650 F the structure shown by the light micrograph at 2500 × in Fig. 9 results. From this micrograph it is evident that the marked acicular structure observed in specimens transformed at the lower temperatures has begun to disappear and only occasional needles are found. Upon examining this structure under the electron microscope at 15,000 × (Fig. 10) certain structural differences are apparent.

1. The carbide particles observed in this structure tend to be larger than those in the lower temperature products. The shape of the carbide has also changed to a certain extent. Instead of the small thin platelets, long plates of carbide are found which appear in section as "stringers."

2. The major portion of the structure consists of small, irregularly shaped areas in which the carbide plates are arranged in a regular fashion. In general, the carbides within these small areas lie in either a parallel or fan-shaped array which imparts an oriented appearance to the area.

3. Some scattered needle-shaped areas still exist (also indicated by the light micrograph of this structure, Fig. 9). These areas, however, constitute a minor portion of the total structure. Unlike those of lower bainite, these needles do not exhibit the characteristic 55 deg cross-striated pattern. The very thin carbide plates are still arranged in a parallel array, but are oriented in a direction more nearly parallel to the needle axis.

From the above observations it is evident that the characteristic lower bainite structure has disappeared and that a transition to a different structure, although not abrupt, has taken place in the temperature range between 600 and 650 F. The microstructure has changed from one consisting predominately of needles, cross-striated with small carbide platelets, to a structure with oriented areas wherein the carbide is parallel to the longer dimension.

Figures 11 and 12 are electron micrographs of the structures formed at 600 and 650 F, respectively, after etching the specimens more deeply. Here, increased etching brings out some of the microstructure more clearly. At 600 F the characteristic cross-striated needles of lower bainite are very evident, (Fig. 11), while at 650 F the almost complete alteration of carbide orientation is notable (Fig. 12); long carbides now are oriented parallel to the length of an area. The deeper etch in these two micrographs increases the apparent size of the carbides.

The structure formed upon isothermal transformation at 700 F is shown in Fig. 13 as it appears under the light microscope at 2500 ×. Examination of this micrograph provides little information concerning the size and distribution of the carbide. The electron microscope reveals the carbide phase more distinctly at the same magnification (Fig. 14). However, an electron micrograph of the structure at 15,000 ×, Figure 15, shows that most of the carbide is in the form of relatively large particles, or plates, which

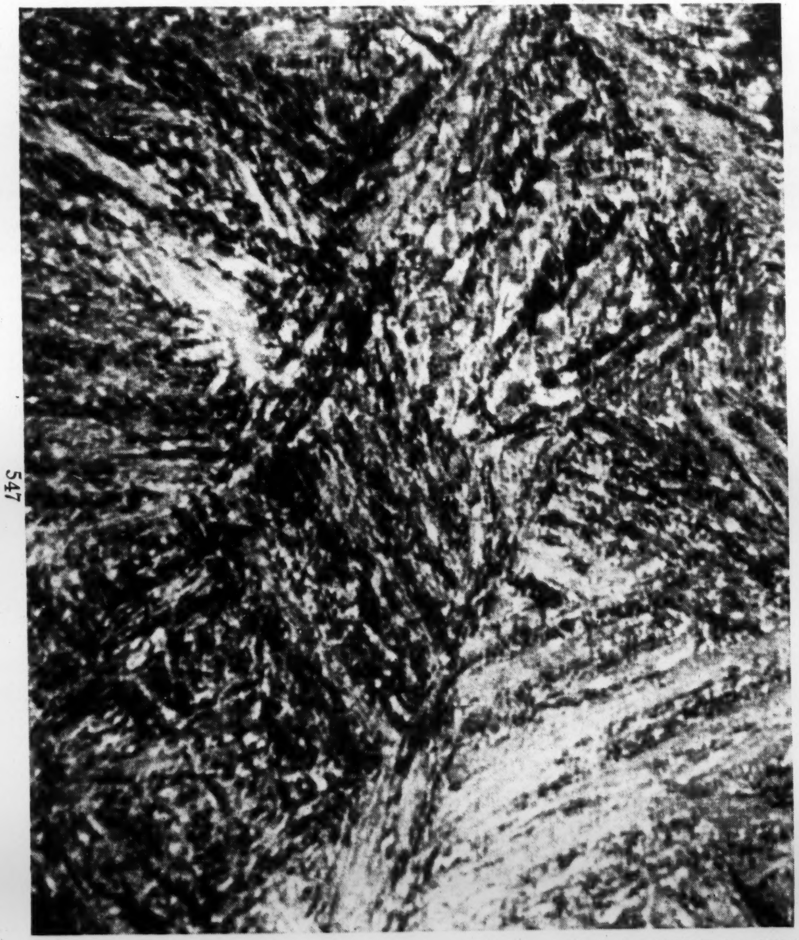

FIG. 2.—Light Micrograph of Bainite Isothermally Transformed at 500 F (× 2500).

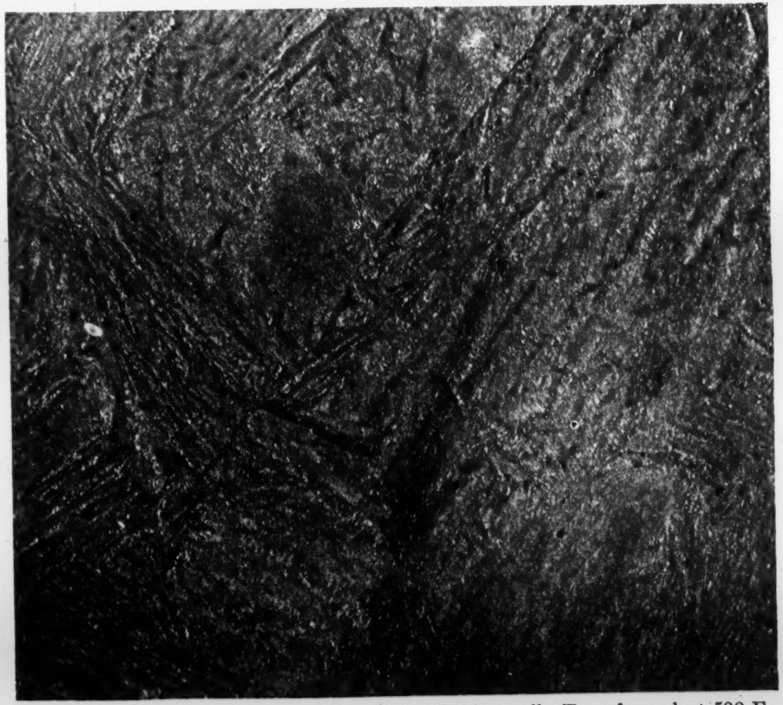

FIG. 3.—Electron Micrograph of Bainite, Isothermally Transformed at 500 F.

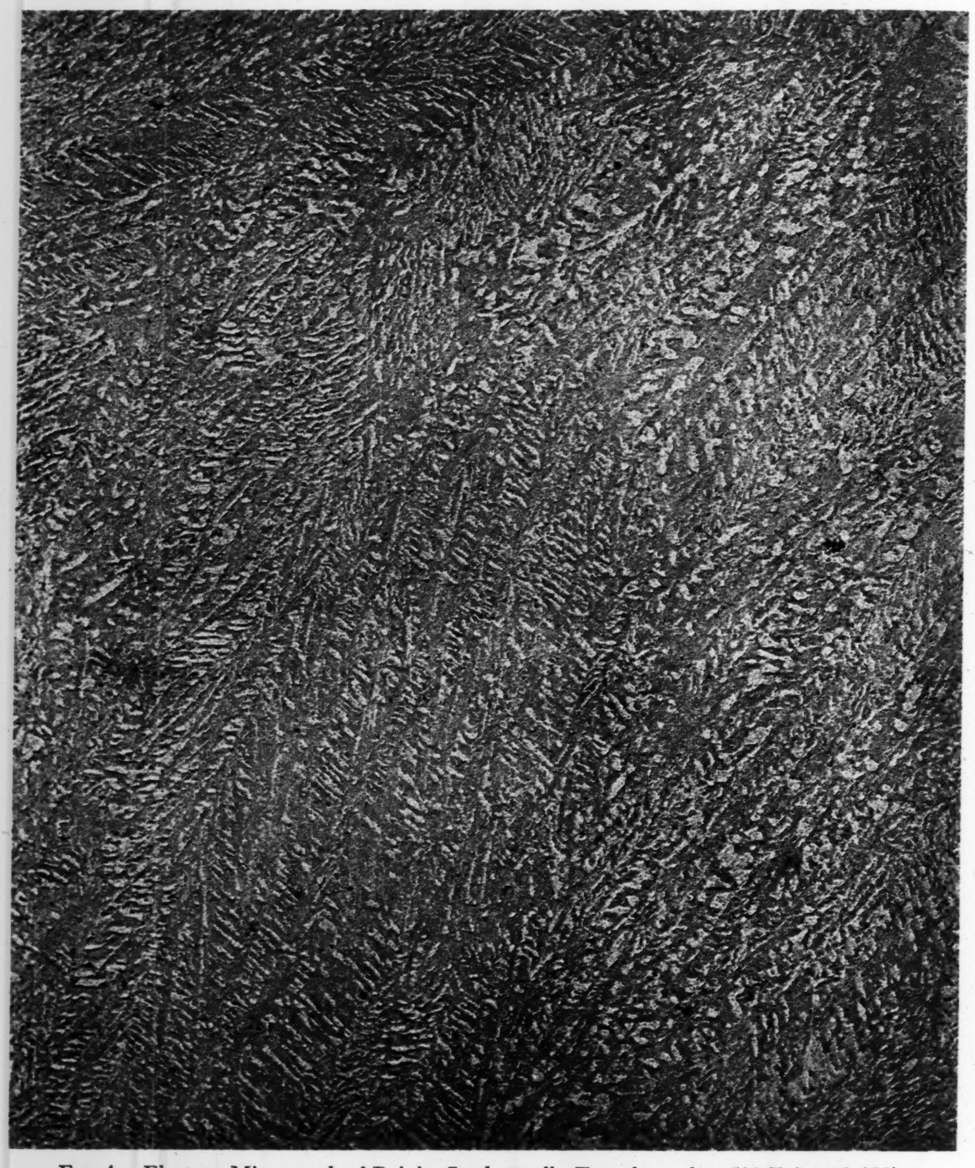

FIG. 4.—Electron Micrograph of Bainite Isothermally Transformed at 500 F (× 15 000).

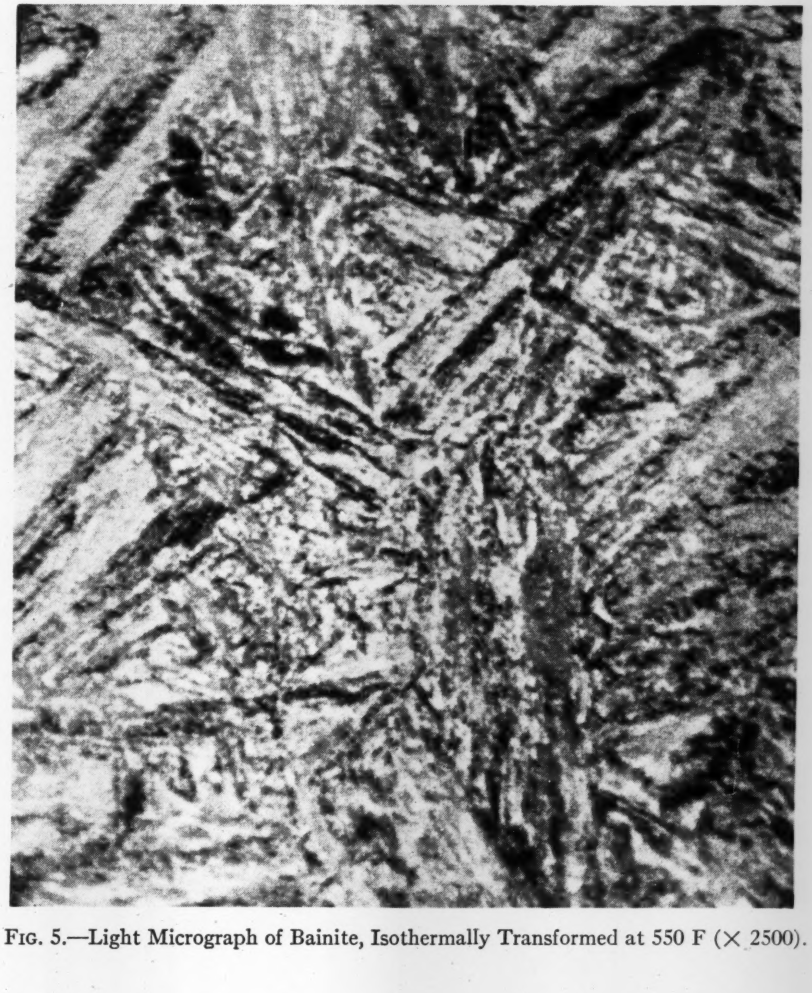

FIG. 5.—Light Micrograph of Bainite, Isothermally Transformed at 550 F (× 2500).

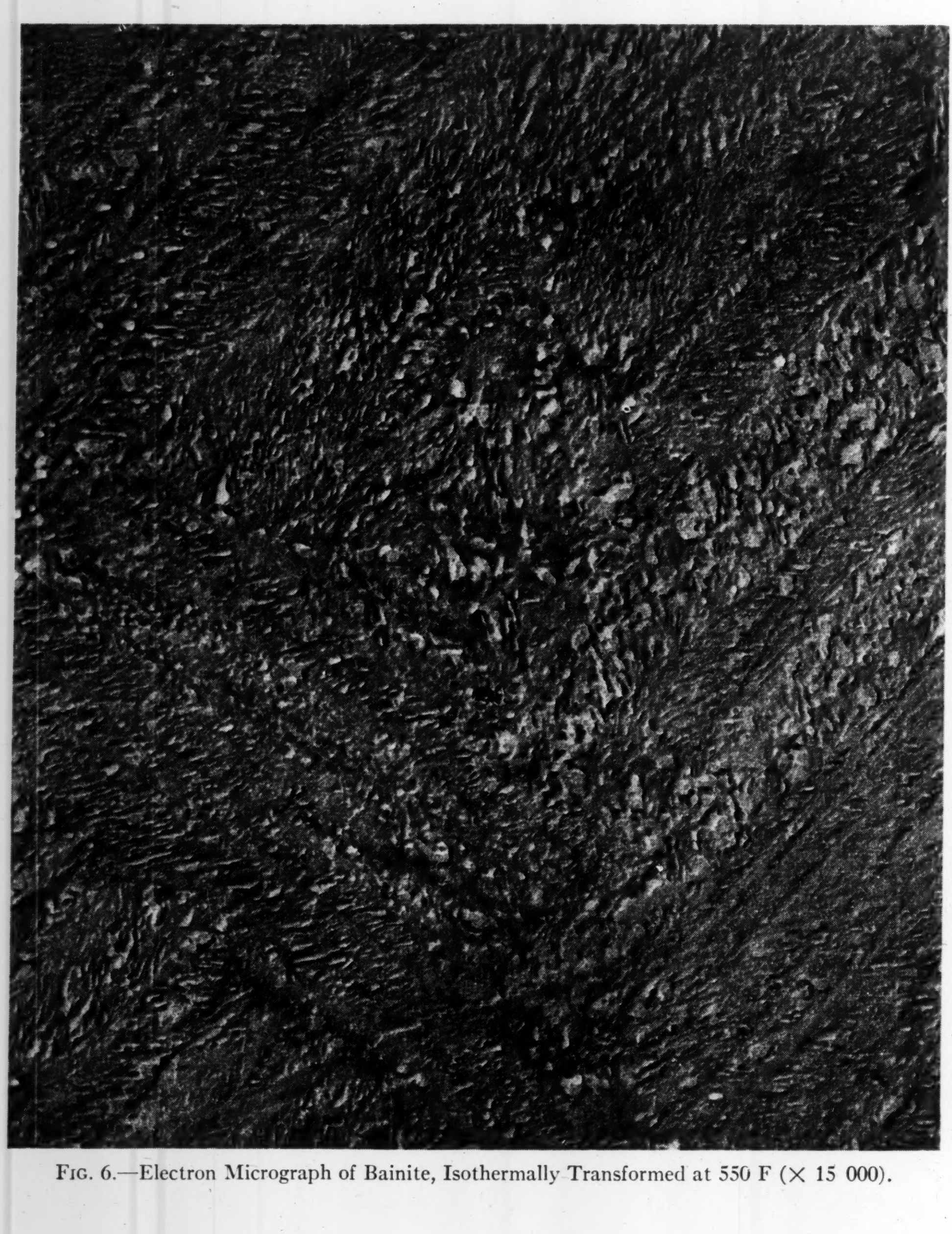

FIG. 6.—Electron Micrograph of Bainite, Isothermally Transformed at 550 F (× 15 000).

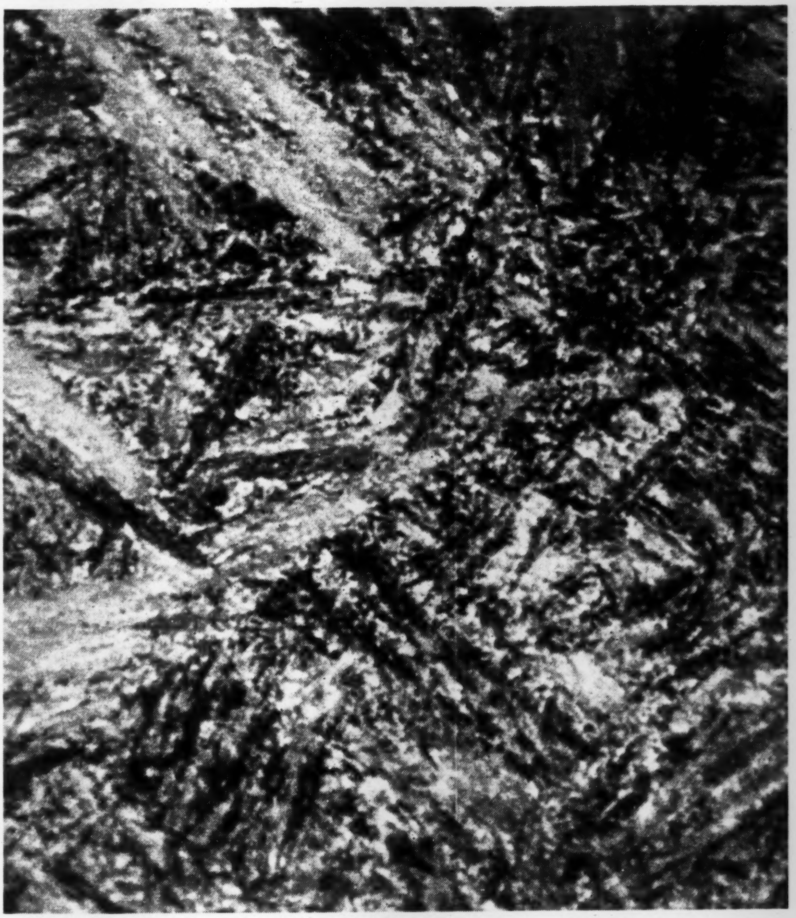

FIG. 7.—Light Micrograph of Bainite, Isothermally Transformed at 600 F (× 2500).

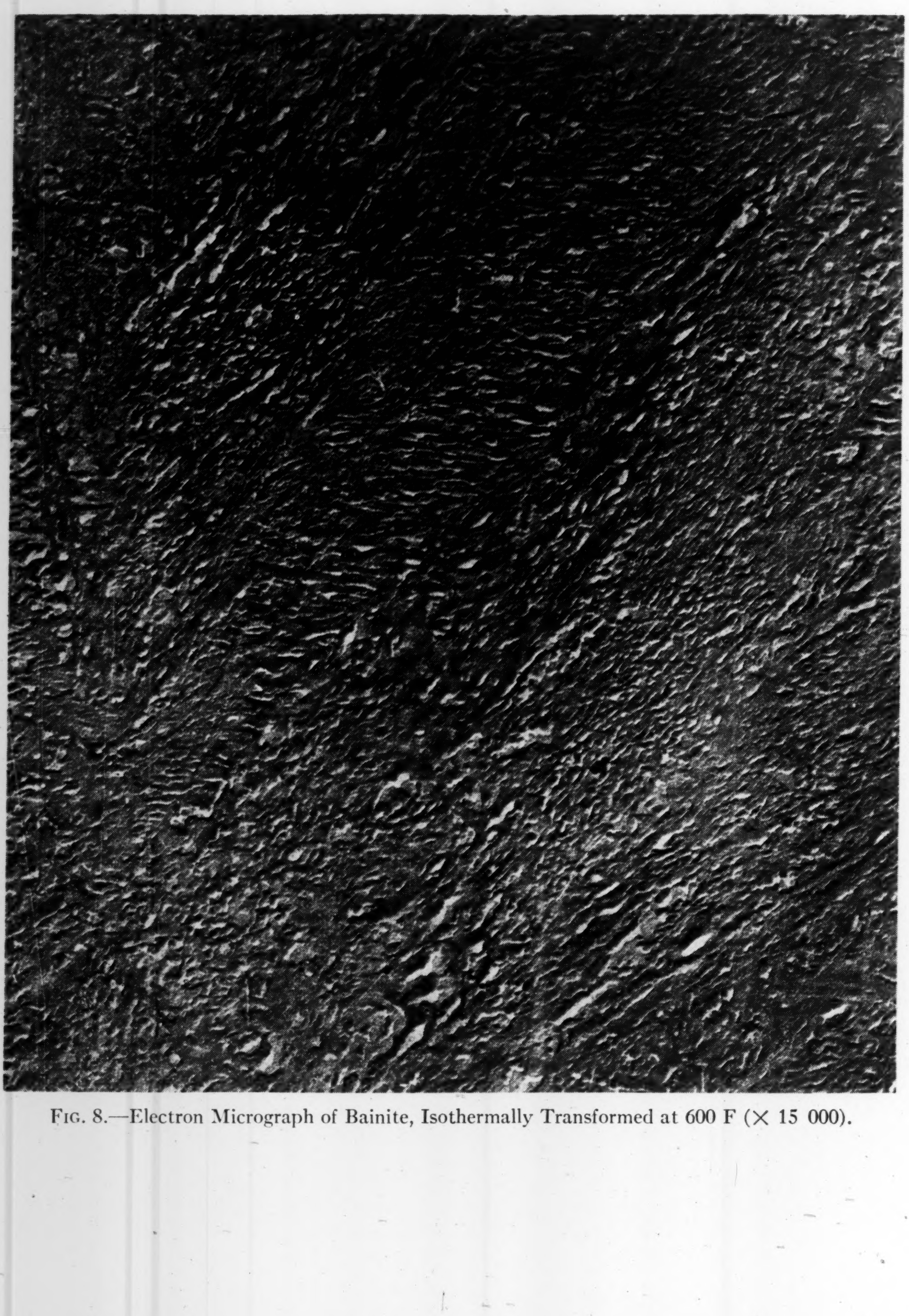

FIG. 8.—Electron Micrograph of Bainite, Isothermally Transformed at 600 F (× 15 000).

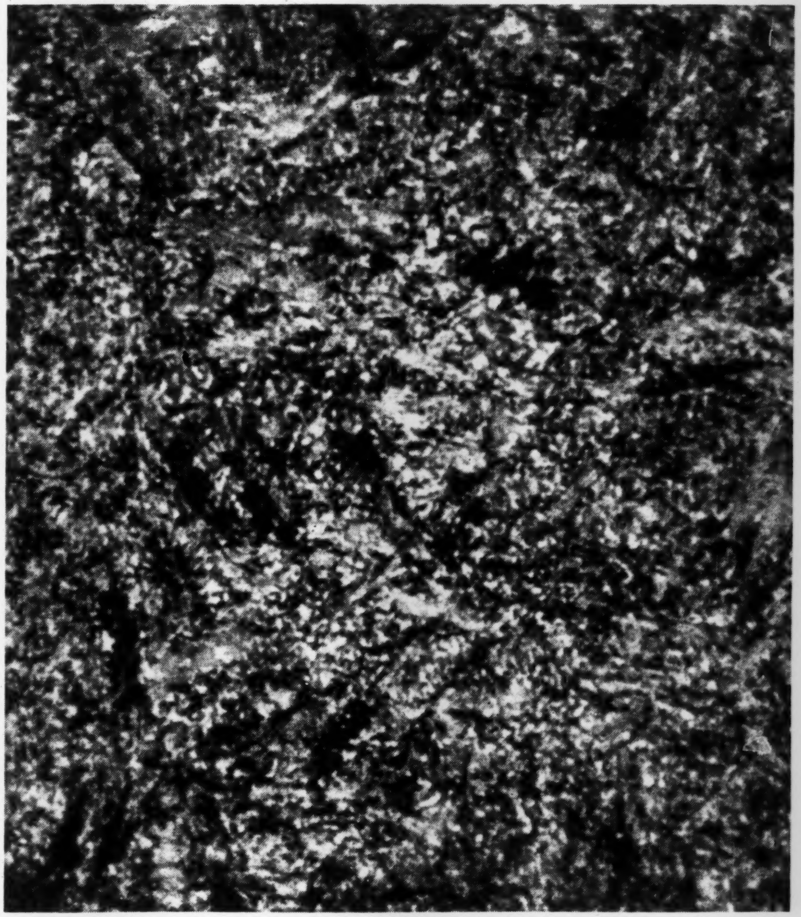

FIG. 9.—Light Micrograph of Bainite, Isothermally Transformed at 650 F (× 2500).

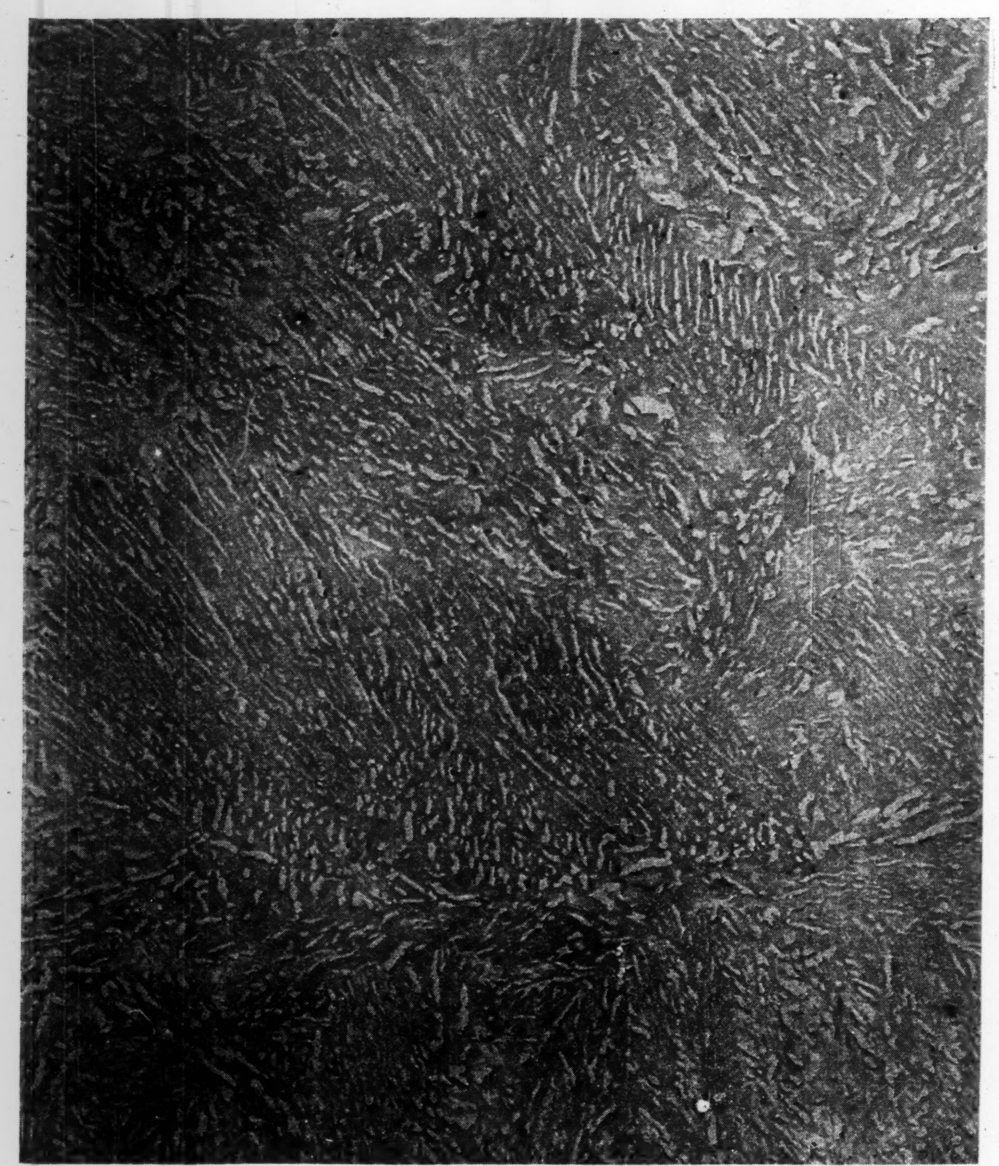

FIG. 10.—Electron Micrograph of Bainite, Isothermally Transformed at 650 F (× 15 000).

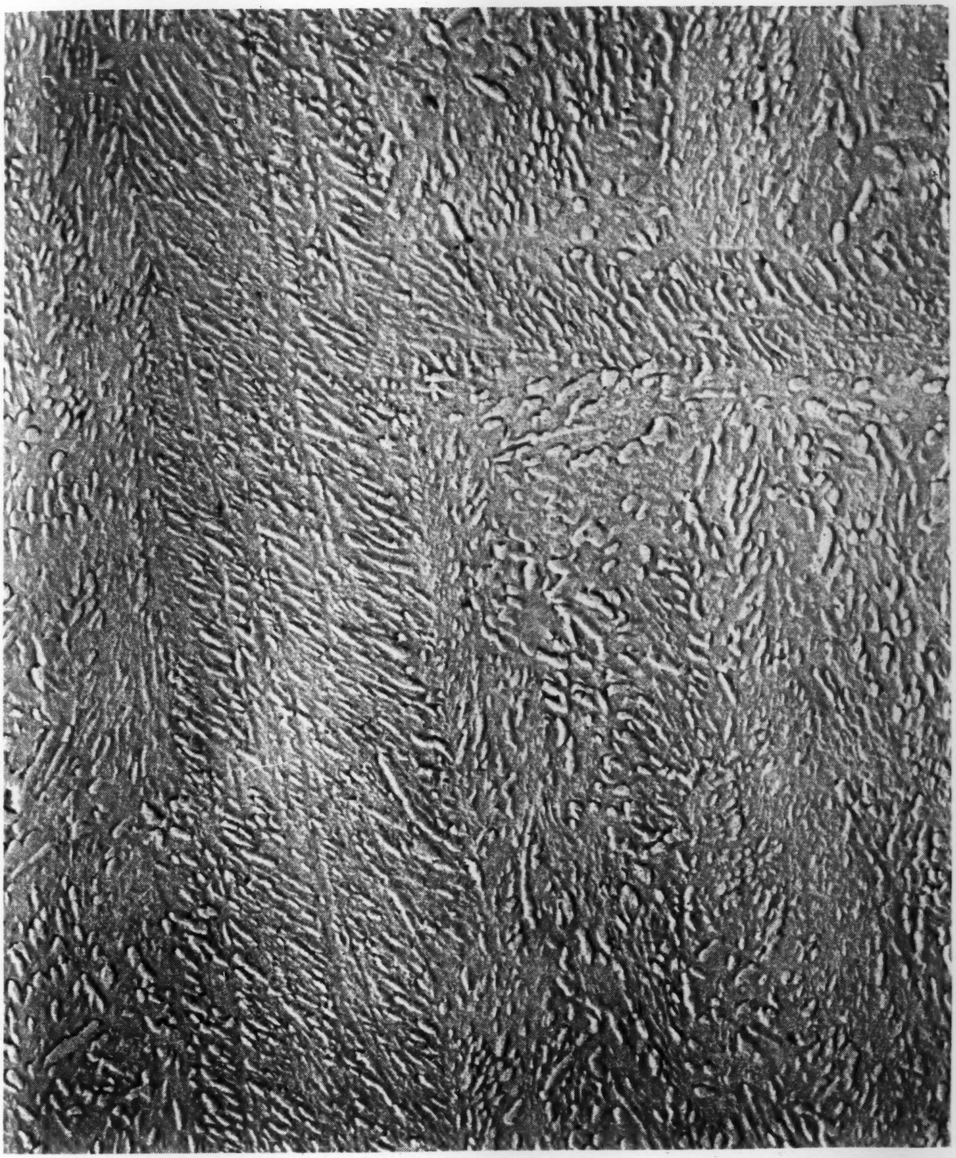

FIG. 11.—Electron Micrograph of Bainite, Isothermally Transformed at 600 F (× 15 000). More Deeply Etched than in Fig. 8 to Bring Out the Cross-Striated Needle Structure of Lower Bainite.

FIG. 12.—Electron Micrograph of Bainite, Isothermally Transformed at 650 F (× 15 000). More Deeply Etched to Emphasize Alteration to Structure Characteristic of Upper Bainite.

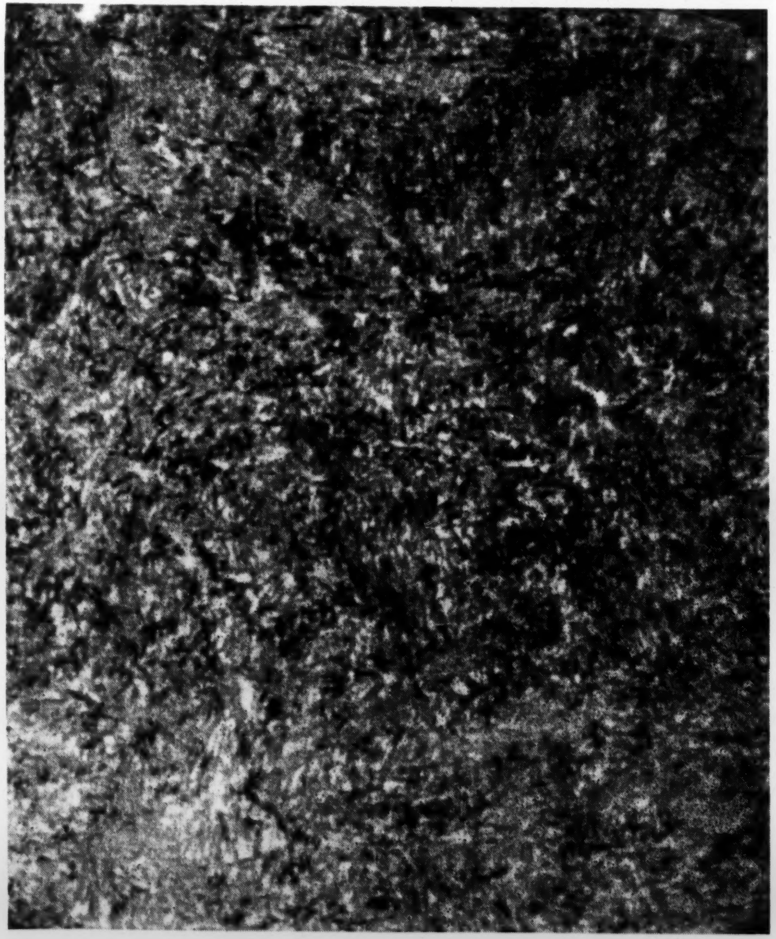

FIG. 13.—Light Micrograph of Bainite, Isothermally Transformed at 700 F (× 2500).

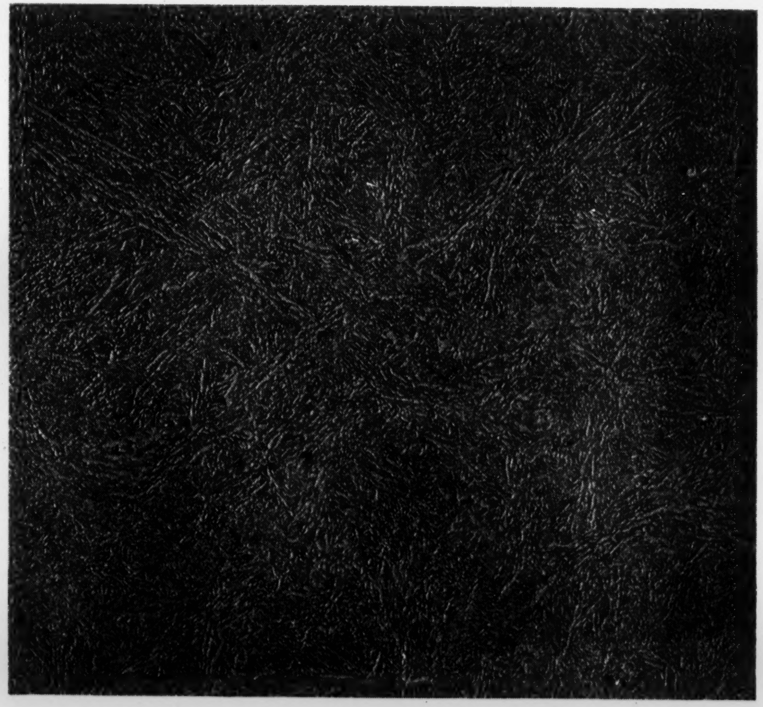

FIG. 14.—Electron Micrograph of Bainite, Isothermally Transformed at 700 F (× 2500).

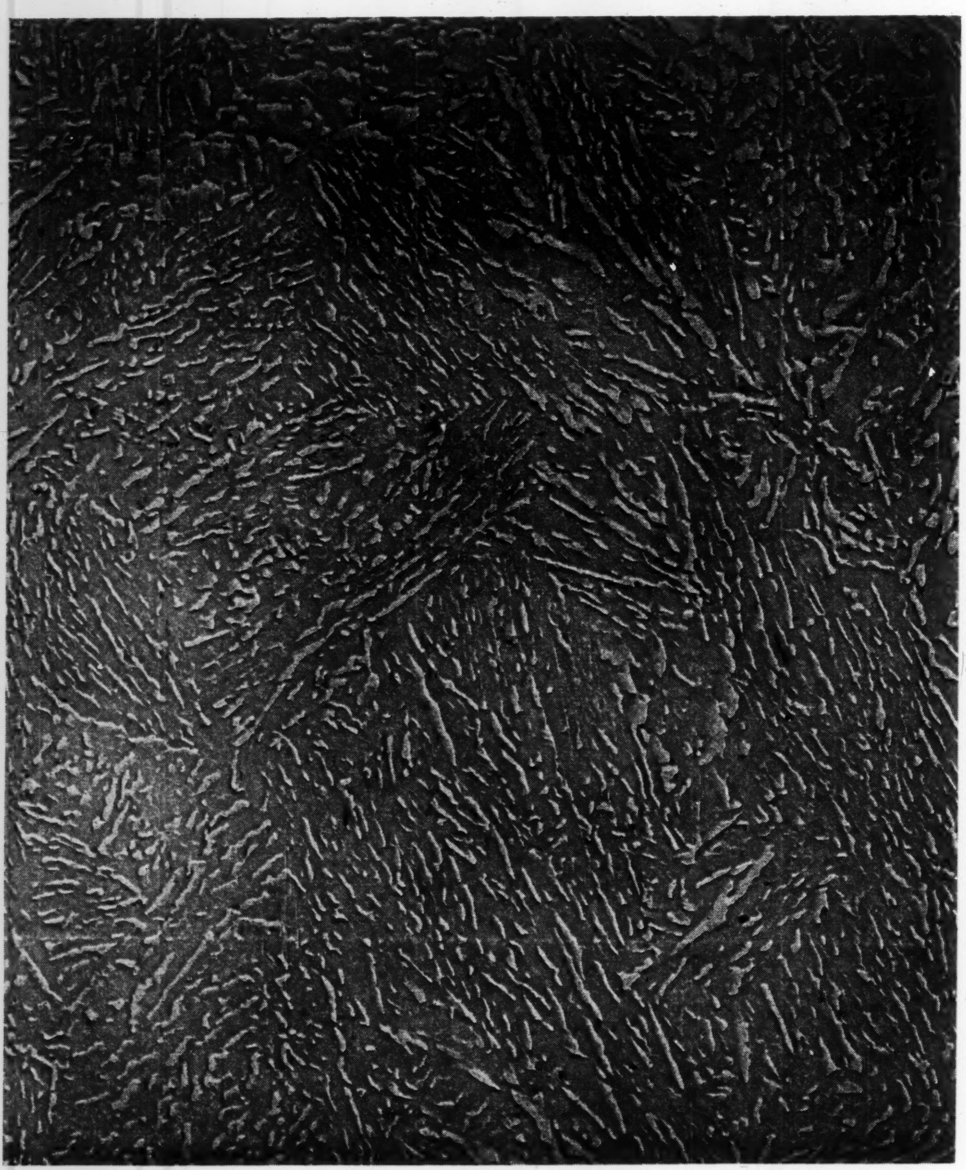

FIG. 15.—Electron Micrograph of Bainite, Isothermally Transformed at 700 F (× 15 000).

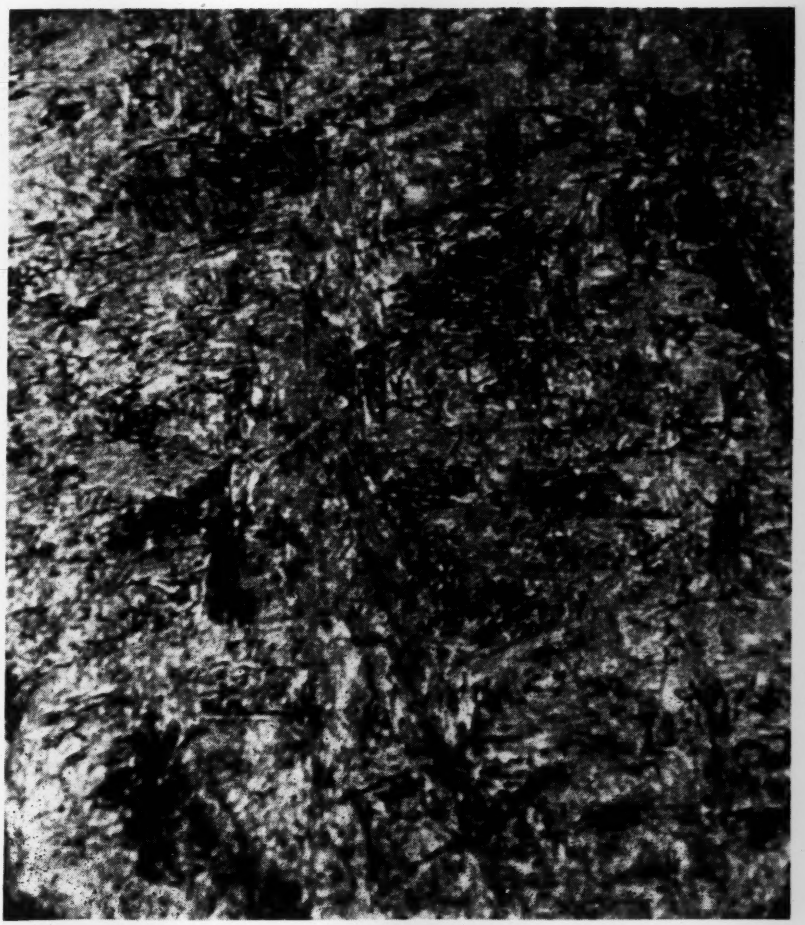

FIG. 16.—Light Micrograph of Bainite, Isothermally Transformed at 750 F (× 2500).

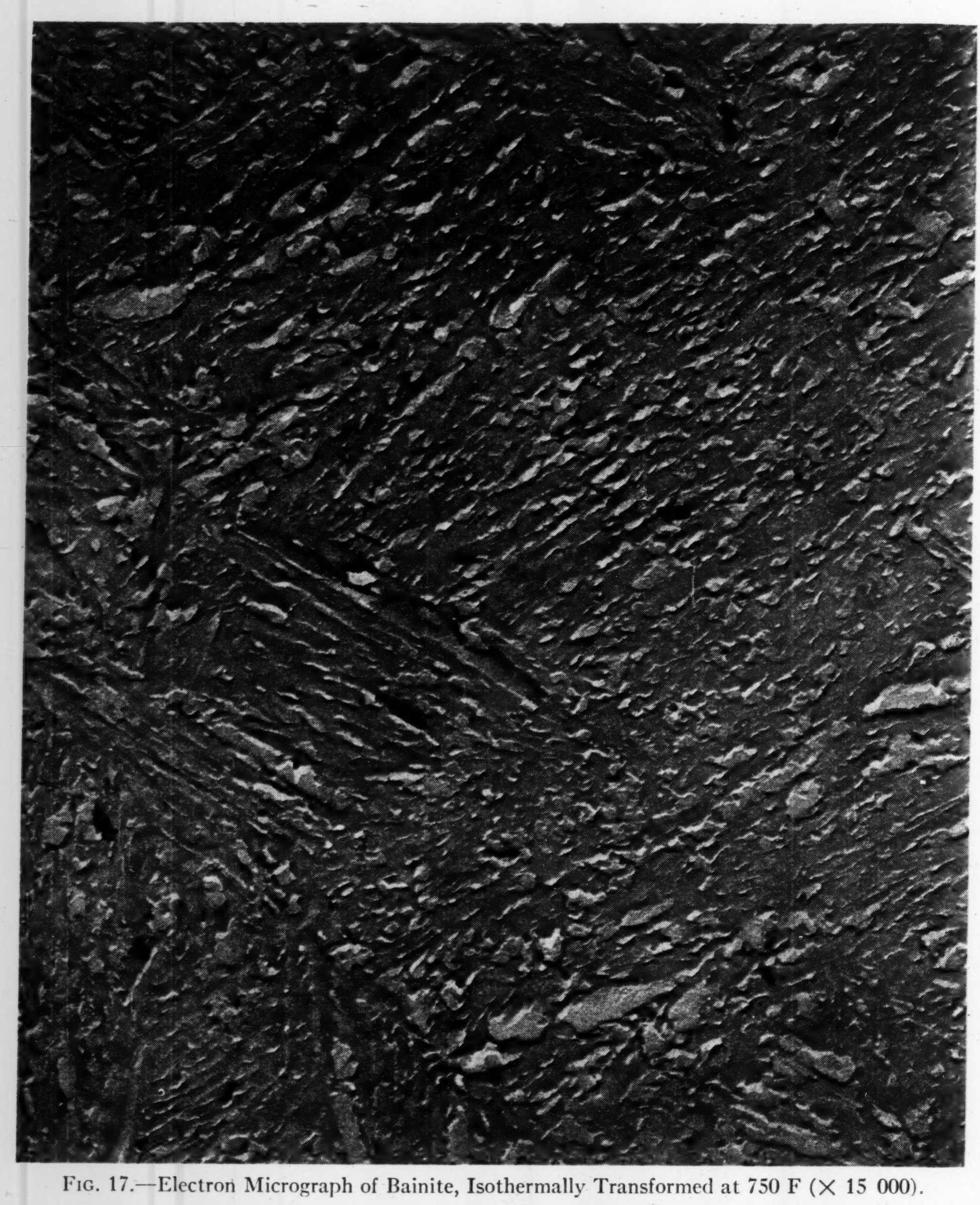

FIG. 17.—Electron Micrograph of Bainite, Isothermally Transformed at 750 F (× 15 000).

FIG. 18.—Light Micrograph of Specimen Transformed about 20 per cent to Bainite by Isothermal Treatment—12 sec at 850 F (× 2500).

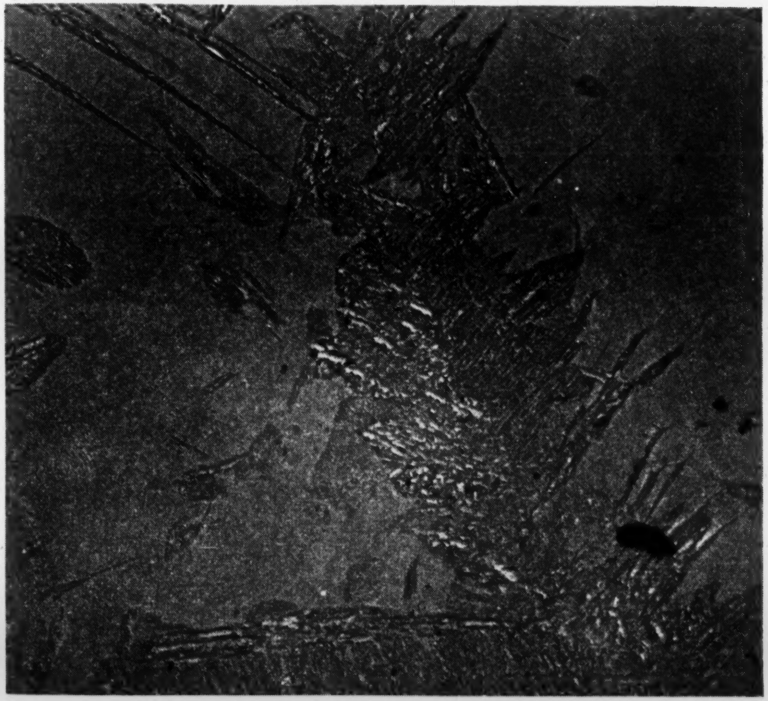

FIG. 19.—Electron Micrograph of Fig. 18 (× 2500).

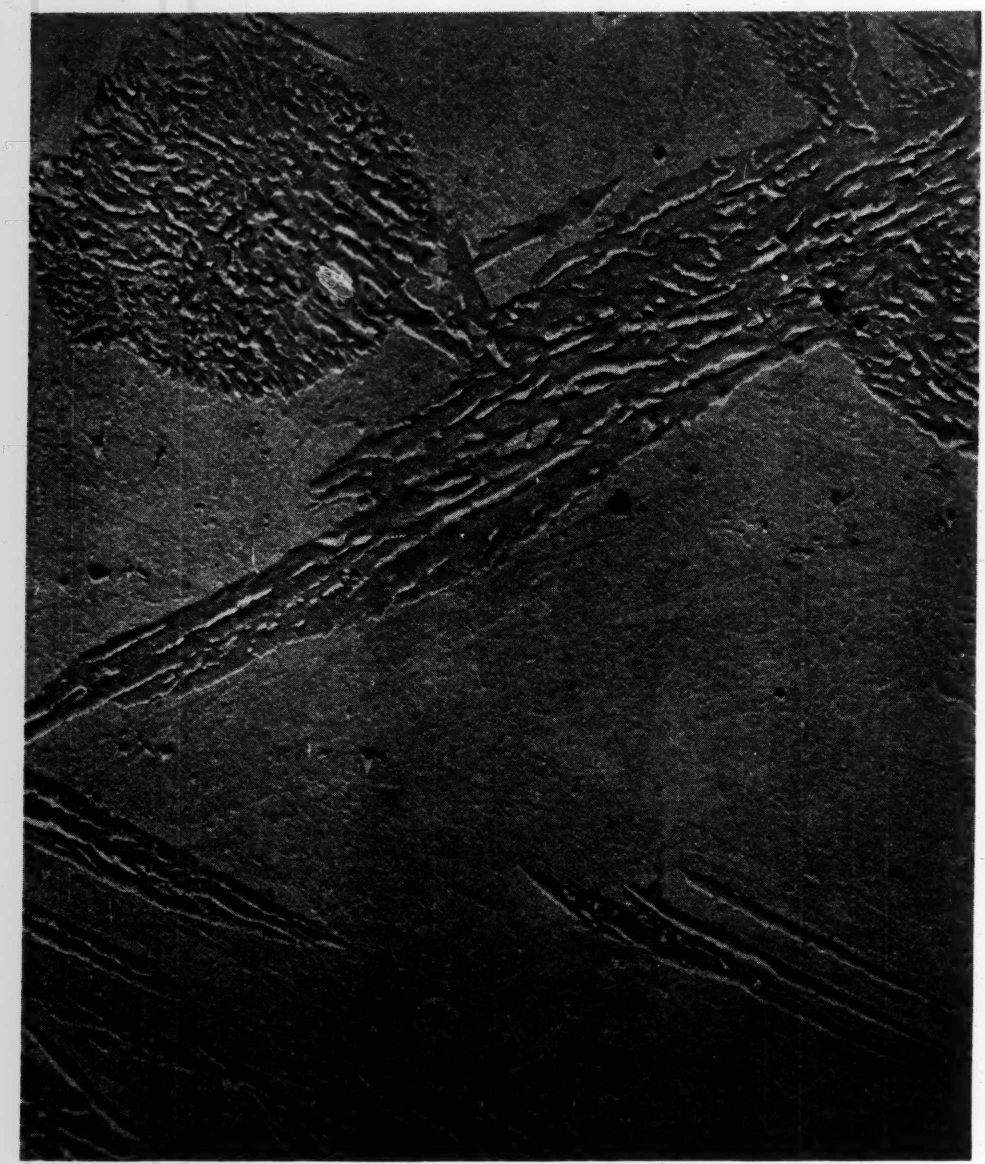

FIG. 20.—Electron Micrograph of Specimen Transformed about 20 per cent to Bainite by Isothermal Treatment—12 sec at 850 F (× 15 000).

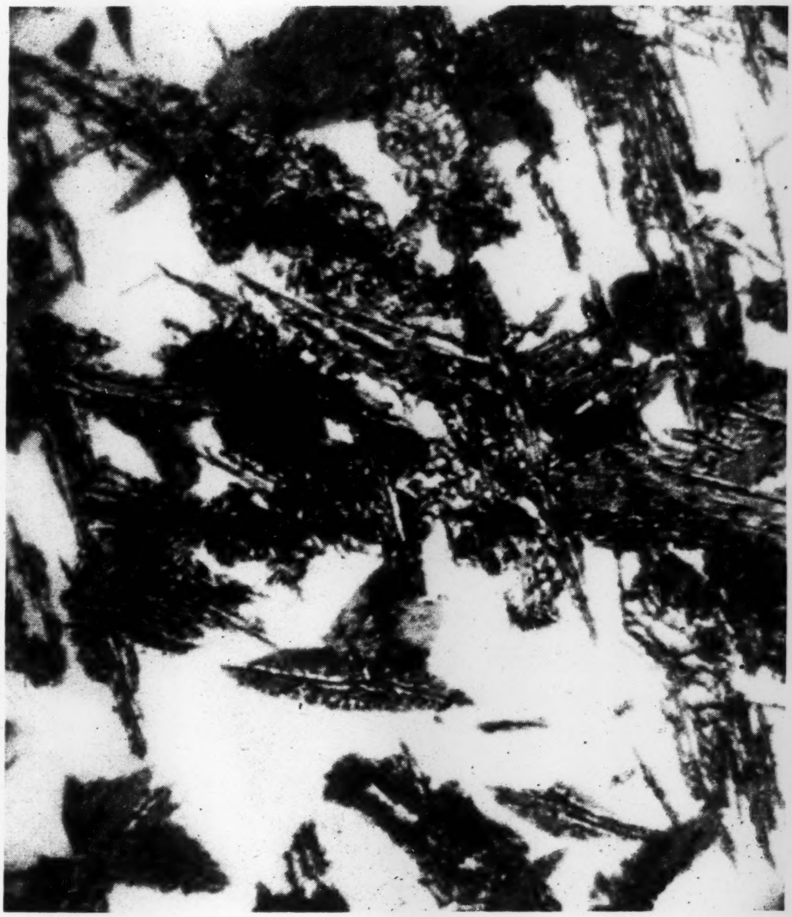

FIG. 21.—Light Micrograph of Specimen Transformed about 50 per cent to Bainite by Isothermal Treatment—20 sec at 850 F (× 2500).

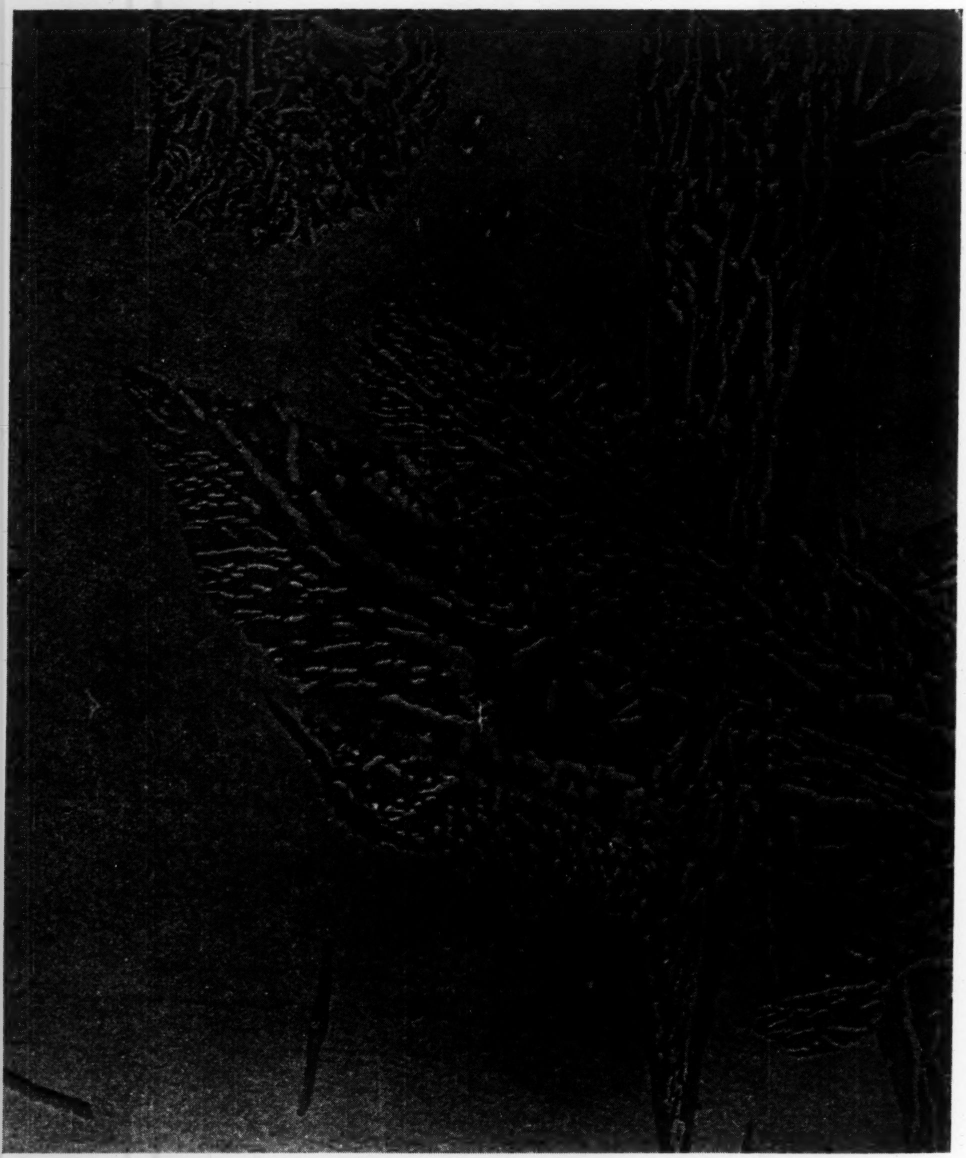

FIG. 22.—Electron Micrograph of Specimen Transformed About 50 per cent to Bainite by Isothermal Treatment—20 sec at 850 F (× 15 000).

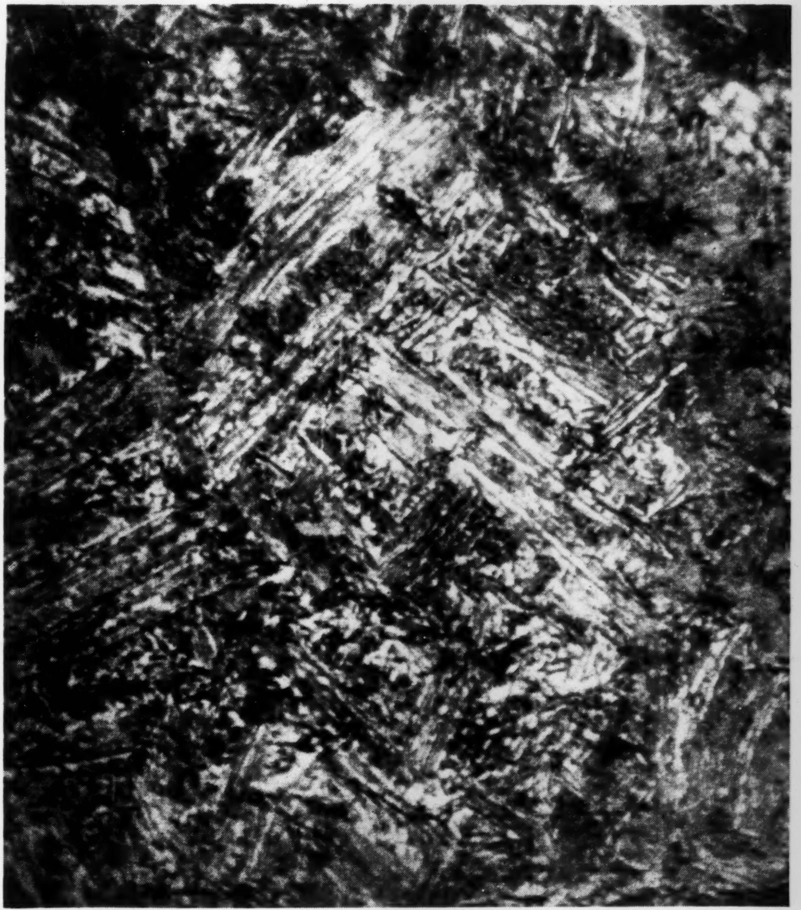

FIG. 23.—Light Micrograph of Specimen Fully Transformed to Bainite by Isothermal Treatment —2 min at 850 F (× 2500).

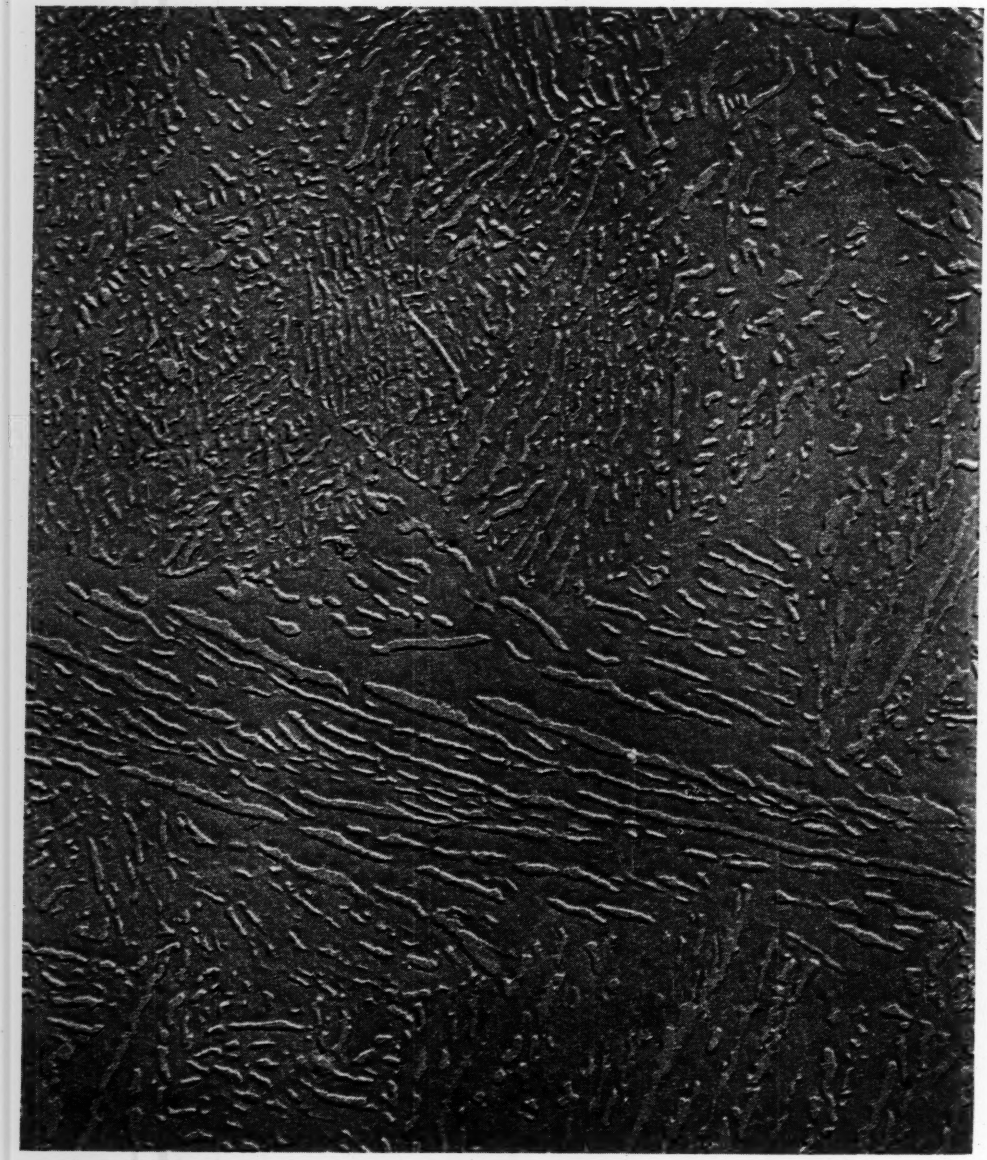

FIG. 24.—Electron Micrograph of Specimen Fully Transformed to Bainite by Isothermal Treatment—2 min at 850 F (× 15 000).

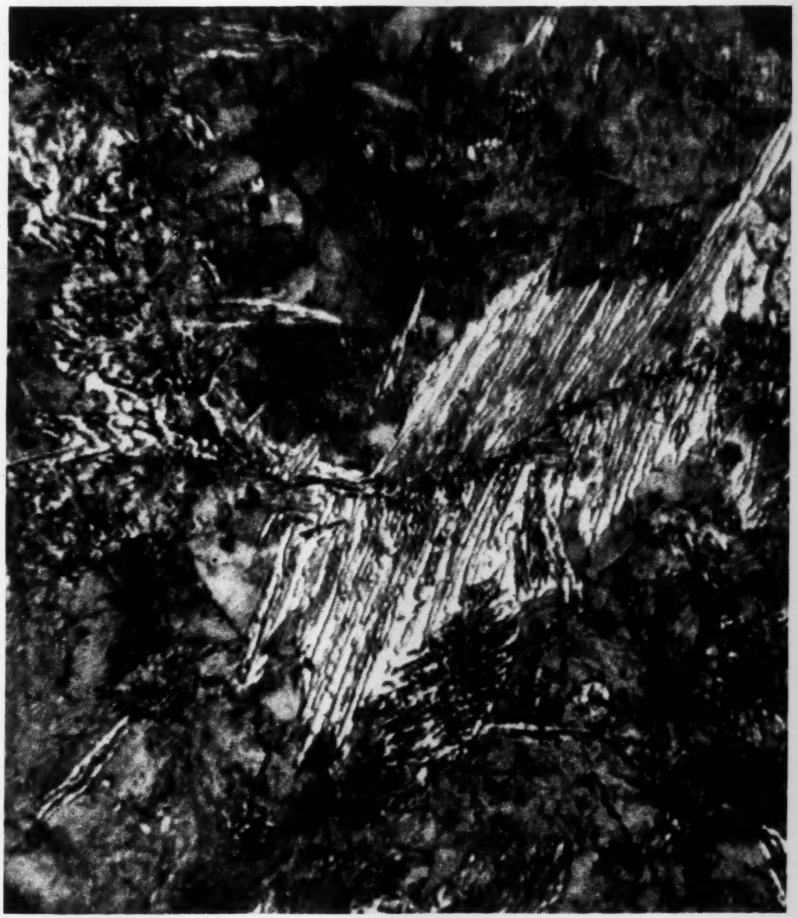

FIG. 25.—Light Micrograph of Bainite and Fine Pearlite Isothermally Transformed at 950 F (× 2500).

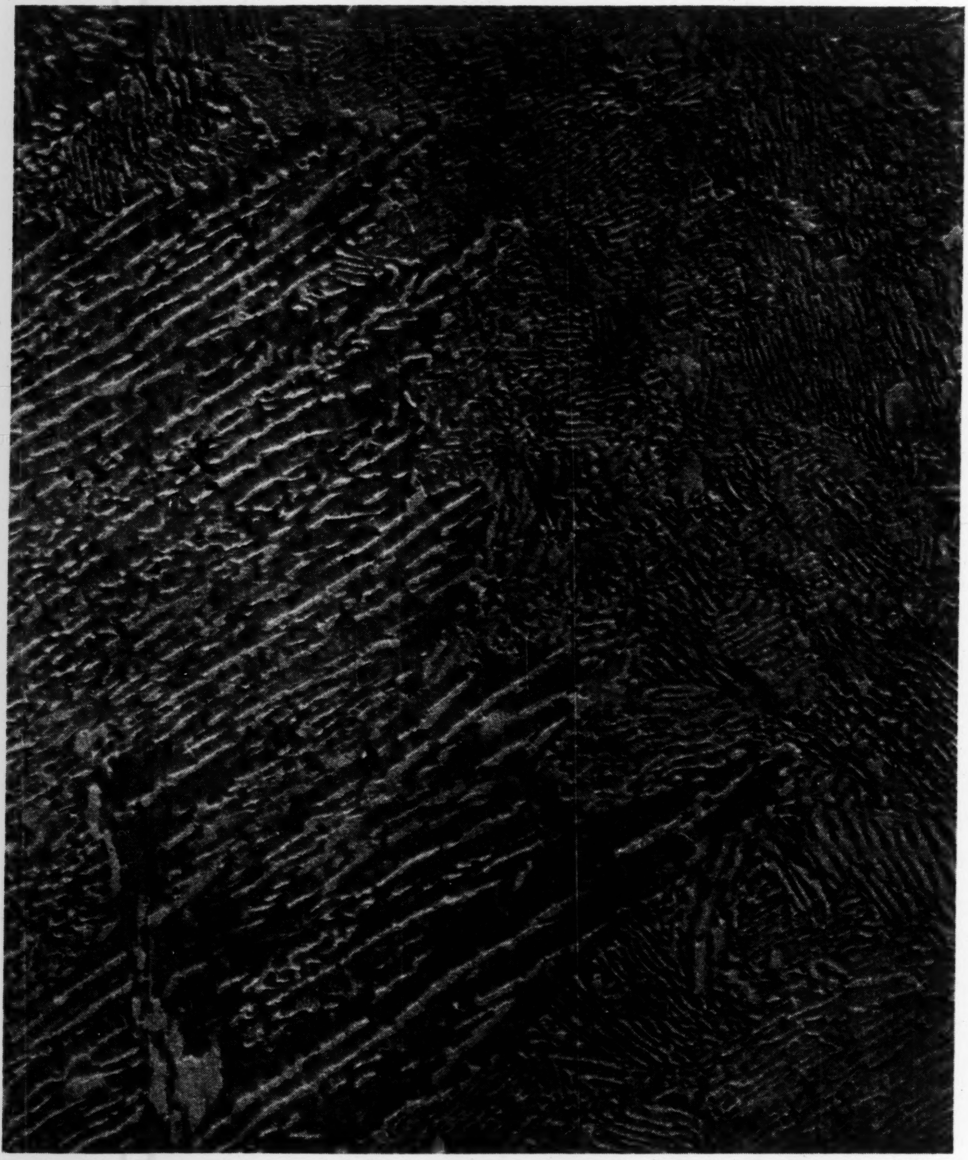

FIG. 26.—Electron Micrograph of Bainite and Fine Pearlite Isothermally Transformed at 950 F (× 15 000).

appear as long stringers in the plane of the polished surface. Within most areas, the stringers tend to have approximately the same orientation, generally parallel to the longer dimension of the area. Those areas in which the carbides appear randomly dispersed arise when a needle is sectioned transversely. The parallel array of carbide particles within a small oriented area is not satisfactorily resolved by the light microscope.

The structure formed upon isothermal transformation at 700 F strongly resembles the bainite structure formed at 750 F, which was examined previously by the committee. However the carbide particles and length of needles are not so large as those formed at 750 F. Light and electron micrographs of the structure obtained at 750 F are shown in Figs. 16 and 17, respectively.

As stated earlier in this report, the committee proposed to investigate the nature and mode of formation of upper bainite in greater detail by examining specimens which had been partially transformed in the upper bainite temperature range. Previous work on specimens of this steel[1] transformed in this region showed that patches of upper bainite found in specimens transformed isothermally at 950 F have a feather-like appearance under the light microscope at 2500 × (Fig. 25). When examined under the electron microscope at higher magnifications, the branches of these "feathers" are shown to be coarse carbide plates arranged in a parallel fashion (Fig. 26). The above micrographs also show that much of the microstructure of specimens transformed at 950 F consists of fine pearlite.

The transformation temperature chosen for the investigation of the nature and mode of formation of upper bainite was 850 F, in order to avoid possible interference by coexisting fine pearlite. Furthermore, the upper bainite structure formed at this temperature is relatively coarse and well-defined. An electron micrograph of the 20 per cent transformed structure at 850 F is shown in Fig. 18 and the corresponding electron micrograph, also at 2500 ×, in Fig. 19. The feather-like appearance frequently observed in light micrographs is evidently a manifestation of the long parallel carbide stringers in a ferrite matrix which are clearly revealed in the electron micrograph of this structure at 15,000×, Fig. 20.

As shown by the electron micrograph, Fig. 20, bainite in the very early stages of transformation frequently exists as single plates (appearing as needles when sectioned). It will also be noted that the advancing transformation "front" of the bainite area appears like the point of a needle whose tip consists essentially of ferrite, with little or no carbide. There is generally a sheath of ferrite around the carbide in bainite, as illustrated by the platelet at the lower left hand side of the micrograph. Figure 20 also shows some small needles arrested at an early stage of transformation, these small needles consisting entirely of ferrite where the plane of the polished surface has not cut through the carbide.

The microstructure of the specimen transformed 50 per cent (20 sec at 850 F) is shown at a magnification of 2500 × in Fig. 21. It will be noted that, at this stage of the transformation, the structure is less feathery in appearance than that in the 20 per cent transformed specimen. The structure of this 50 per cent transformed specimen is shown at a much higher magnification (15,000 ×) in the electron micrograph of Fig. 22. From this micrograph, it is evident that at this later stage in the transformation, the individual bainite areas have grown longer and considerably broader. The relatively fast rate of growth in the breadth direction and the development of smaller intersecting bainite areas, probably explain why this structure appears less feathery than that of the 20 per cent transformed specimen. The plane sectioning the bainite frequently reveals a leaf-like structure, with a central rib of carbide along the axis, surrounded by radiating needles (or plates) of carbide (Fig. 22).

An electron micrograph of the fully transformed structure is shown in Fig. 23 and the corresponding electron micrograph in Fig. 24. Some portions of the light micrograph of this structure are partially resolved; presumably, these represent regions in which long carbide stringers occur, as more clearly revealed in the electron micrograph. Most of the stucture, however, is not resolved by the light microscope and appears as gray patches in the light micrograph. Under the electron microscope, on the other hand, the structure of this fully transformed 850 F bainite is seen to be very similar to that of the fully transformed structures at 650 to 750 F, except that the carbide particles are, generally, somewhat larger. The areas between the coarse carbide stringers are made up of smaller intersecting bainite structures.

Also observed are fine carbides which are arranged in a regular, somewhat parallel, fashion resembling those found in fine pearlitic structures formed at higher temperatures. It has already been shown[1] that both upper bainite and fine pearlite are formed.

CONCLUSIONS

The results obtained from the electron metallographic examination of bainitic structures in eutectoid carbon steel lead to the following conclusions.

1. The majority of the carbides found in lower bainite are extremely small, plate-like particles arranged in parallel array within long, narrow ferrite needles. The small carbide platelets appear as cross-striations at an angle of 55 deg to the ferrite needle axis. Because of their plate-like nature, the apparent difference in size of these particles in different needles is largely due to differences in orientation.

2. Based upon the disappearance of the characteristic cross-striated needles of lower bainite, the transition from lower to upper bainite occurs in the transformation temperature range between 600 and 650 F.

3. The transition from lower to upper bainite is characterized by two distinct changes in the microstructure. First, the size, shape, and orientation of the carbide particles change from extremely small platelets arranged in parallel array at an angle of approximately 55 deg with respect to the axis of the bainite needles, to larger carbide particles and stringers arranged more nearly parallel, lengthwise. Second, the needles of ferrite which account for the marked acicular nature of lower bainite disappear. In their place appear small irregularly-shaped areas in which the carbide particles and stringers are arranged in parallel fashion, with their length in the direction of the longer dimension of the area.

4. As the temperature of transformation is further increased above the transition range, the size of the individual upper bainite areas increases and the carbide stringers become larger and longer.

5. Electron micrographs of specimens partially transformed to upper bainite at 850 F show the structure to consist of stringers of carbide surrounded by a sheath of ferrite. Similarly, "feathery bainite" is a parallel array of carbide needles or plates, in a ferrite matrix.

6. In the initial stage of the transformation, individual platelets (seen as needles) are formed. As the transformation progresses, there is a relatively fast

increase in breadth of these long, coarse bainite areas.

7. Small amounts of fine pearlite can co-exist with upper bainite in this steel at transformation temperatures as low as 850 F.

Although preliminary electron diffraction indicates the presence of some hexagonal ϵ-iron carbide in bainite transformed at 500 F, the results suggest that the carbide platelets are cementite in the cross-striated needle structure in 550 and 600 F lower bainite.

FUTURE WORK

During 1952 and 1953, Subcommittee XI plans to investigate the following phases of this work on eutectoid steel more intensively:

1. The changes in microstructure which occur when bainite is tempered. Specimens of bainite will be transformed at various temperatures, then tempered under conditions comparable to those for the tempered martensite samples already studied,[1] in order to permit comparison.

2. Additional electron diffraction measurements will be made to confirm the preliminary results regarding the occurrence of ϵ-iron carbide and cementite.

3. Specimens of bainite isothermally transformed at temperatures just above the M_s temperature will be prepared. Examination of the microstructure with the electron microscope may give information about extreme lower bainite. Electron diffraction measurements of these specimens should yield data on the occurrence of ϵ-iron carbide.

4. The effect of various etchants and depths of etch on the different microstructures is being investigated and the results will be reported.

DISCUSSION

MR. C. W. MASON.[1]—The parallel platelets within the needles in samples of lower bainite raise a number of questions:

1. Their 55-deg angle can hardly be constant, because if the plane of polish is assumed to be parallel to the axis of the needle but in a different azimuth (equivalent to rolling the needle over) this angle might have any value less than 55 deg. The fact that the 55-deg angle does seem to be frequent points to the possibility that rodlets rather than platelets exist, for rodlets would not exhibit elongation and parallelism unless surfaced approximately lengthwise.

2. If the needles are ferrite, it is hard to see why there is a single orientation of the platelets (or rodlets) within them, since there is no unique crystallographic plane or direction in cubic crystal structure which ferrite possesses. If the formation of these five structures is by precipition from ferrite, any geometrical arrangement should be multidirectional, in accordance with the Widmanstätten mechanism. It therefore seems probable that the formation of the substructure within the needles of lower bainite involves a shear, as is the case in the needles of martensite.

3. This raises the question as to whether a dividing line can be drawn between the structures of lower bainite and slightly tempered martensite on the basis of appearance with the electron microscope, without dependence on rate of etching or other external criteria. It points to the desirability of investigating bainites formed below Ms and of correlating etching rate and tempering times for these structures that may be distinguishable as "knowns" but appear very similar to those who have not controlled their history and preparation.

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[1] Professor of Metallurgy, Cornell University, Ithaca, N. Y.

Any study of bainite cannot ignore the question of noneutectoid compositions and the structural gradation that exists from fine proeutectoid ferrite to upper bainite. It is hoped that the excellent study of the committee can be directed to this aspect, not as a digression but as contributing directly to the understanding of the origin and nature of the bainite structure which is an ultimate goal of this work.

MR. D. M. TEAGUE (*author*).—The 55-deg angle represents only an approximation frequently observed in the structure. The frequency of this angle is difficult to explain, particularly since the electron micrographs show evidence of plates in some needles, depending on the orientation of the needle. Possibly, the 55-deg cross-striated structure may be revealed by the etchant only in needles with certain orientations.

It is pointed out here as an aid in identifying the lower bainite structure. As such, it is characteristic, though based on rather preliminary evidence on one type of steel.

MR. S. J. ROSENBERG.[2]—Does the committee have any program or plans that include the examination of steels transformed at temperatures just below the Ms? I am referring particularly to the difficulty of differentiating under the microscope between martensite, the formation of which is temperature-dependent only, and bainite, which may form at the same temperature but the formation of which is time-dependent. The martensite so formed is tempered on holding at the temperature of transformation and, so far as the metallurgical microscope is concerned, cannot be differentiated from bainite that forms isothermally at the same temperature.

Can we differentiate between these two structures by means of the electron microscope?

MR. TEAGUE.—The valuable suggestions of Messrs. Mason and Rosenberg regarding the examination of bainite formed below the Ms temperature may aid in distinguishing lower bainite and very slightly tempered martensite. The preparation and examination of such specimens with the electron microscope will be considered by the Subcommittee. We are already planning to investigate a hypo-eutectoid steel, preparing duplicate specimens with a series of representative microstructures, similar to that completed for eutectoid steel.

MR. ALFRED L. ELLIS.[3]—On the basis of my own experience, I think that all of us would be rather hard pressed to distinguish in a positive way between tempered martensite and retained austenite transformed to bainite during tempering. However, I do believe that this represents a beginning in that direction and that further examination and conscious effort to bring out what visual differences there are, if there are any such differences, will be a step in the right direction.

As for differentiating between as quenched martensite and bainite, I think I can say that this is possible, for the same reason that it is possible in the light microscope. It has been my experience that martensite as quenched is a very difficult etching phase. On the other hand, the bainite would be made up of a combination of cementite and ferrite and would tend to etch more rapidly, and then it would be possible to distinguish the bainite. In other words, I think you find in the light microscope generally that you get a dark patch in the midst of the gray martensite background, and this same thing shows up in the electron microscope because of the different etch rates.

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[2] Metallurgist, National Bureau of Standards, Washington, D. C.

[3] Chief Research Physicist, International Harvester Co., Chicago, Ill.

APPENDIX II

PRE-SHADOWED REPLICAS FOR ELECTRON METALLOGRAPHY

By W. L. Grube[1] and S. R. Rouze[1]

Synopsis

Thin evaporated metal films can be stripped successfully from etched metal surfaces by using a parting layer of a surface active agent (Victawet 35B) deposited by vacuum evaporation. This affords a means whereby pre-shadowed plastic or all-metal replicas of metallographic surfaces can be prepared for electron microscopy. These replicas can be direct-stripped without destroying the specimen or otherwise damaging the prepared surface.

Replica resolution is effectively improved by the pre-shadowing technique. Inasmuch as the structure of the plastic replica material is not made visible by shadow-casting, resolution is not limited by this factor. Resolution is further improved because that part of the replica which is in contact with the specimen, and actually reproduces the detail, is made of metal.

Pre-shadowed replicas, when wet-stripped, are free from objectionable strain marks which often arise in direct-stripped plastic replicas. Occasional difficulties, such as the occurrence of holes and tears, can be overcome by the proper control of etch depth and shadow-casting angle.

The improvement in resolution gained by pre-shadowing has been particularly useful in the study of low-temperature tempered steel where the detail of interest is of the same order of size as the plastic structure visible in the shadowed-plastic replicas.

A basic problem which confronts those who wish to use the electron microscope for metallographic studies involves the nature of the instrument itself. Since it is a transmission-type microscope, it cannot be used to examine the surface detail of opaque metal specimens directly. In order to overcome this fundamental difficulty, the electron microscopist has devised means of transferring the surface detail to be studied to thin films called replicas. These films are thin enough to be reasonably transparent to the beam of illuminating electrons and, therefore, can be examined in the transmission-type electron microscope. As in ordinary bright field light microscopy, the electron image is produced by local variations in scattering power which arise from the variations in thickness of the replica. These variations in thickness are brought about by the differences in elevation on the original surface.

Since the replica becomes the specimen that is actually examined in the electron microscope, it is obvious that the over-all resolution in the final image can be no better than the resolution or faithfulness of the replica.

For the purposes of this discussion the term "replica resolution" is defined as the size of the smallest detail in the original specimen that is faithfully reproduced by the replica.

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[1] Research Laboratories Division, General Motors Corp., Detroit, Mich.

Replica resolution is dependent upon two factors. These are: (1) faithfulness of reproduction of the specimen detail in the replica film, and (2) the size of the internal structure of the replica material. In practice, faithful reproduction is generally obtained, at least down to sizes comparable to the size of the structure of the replica material. It can be seen, therefore, that the factor which either directly or indirectly limits the resolution of a replica process is the structure of the replica itself. In order to effect an improvement in the resolution of a particular replica process, it is therefore necessary to use a material which has a smaller internal structure. Furthermore, if it should be necessary to use a material having rather large intrinsic structure for part of the replica, the structure should remain invisible.

It is the purpose of this paper to describe a convenient method whereby the resolution of the replicas used in present practice may be improved without introducing any new difficulties or further complications into the replicating process.

How this improvement in resolution is brought about can be more clearly described by starting, first, with a brief review of present replicating practice. In this review the disadvantages and limitations of present replica procedures will be pointed out and later it will be shown how the more serious limitations can be overcome.

Numerous methods and materials have been found to be suitable for preparing replicas of metal sections and surfaces. The three most important types of replicas, in general use at present, are as follows:

1. Amorphous oxide film,
2. Plastic, and
3. Metal.

The amorphous oxide film type of replica is exceptionally faithful in the reproduction of fine surface details, and at the maximum magnifications possible with the electron microscope this type of replica exhibits little, if any, structure of its own. These qualities make it an ideal type of replica, but unfortunately its use is limited to the study of those metals which form amorphous oxide films upon their surfaces. A typical example is aluminum.

The plastic type of replica is the most widely used, chiefly because of its simplicity. Besides being the easiest to prepare, it also yields micrographs which are the easiest to interpret. Of the three types listed, the plastic replica exhibits the poorest resolution and, as will be shown later, it is the structure of the plastic which limits the resolution of this type of replica.

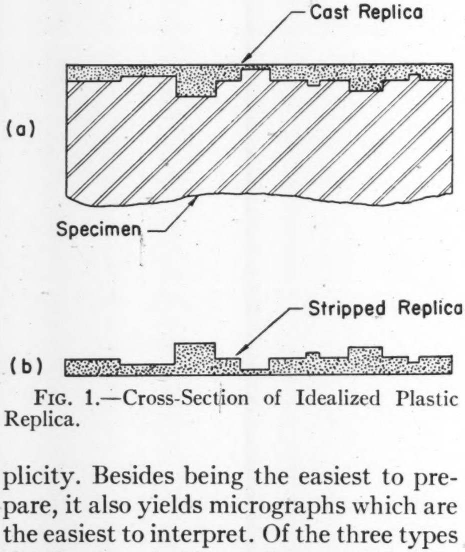

FIG. 1.—Cross-Section of Idealized Plastic Replica.

As Calbick (**1**)[2] has shown, metal replicas prepared by vacuum evaporation exhibit remarkably faithful reproduction of fine detail, and, if made properly of certain metals, their intrinsic resolution is considerably better than that of either plastic or oxide film replicas. Metal replicas suffer the disadvantage that they are extremely fragile to handle and are difficult to remove without destroying the original specimen. Once prepared, however, they are exceptionally rugged and can withstand high intensity exposure to electrons. Thus, each of the generally accepted types of replica possess certain advantages as well as certain limitations.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 589.

Since the plastic type of replica offers the simplest solution to the problem of replication, let us consider first the properties of plastic replicas in more detail and see what can be done to overcome some of their limitations.

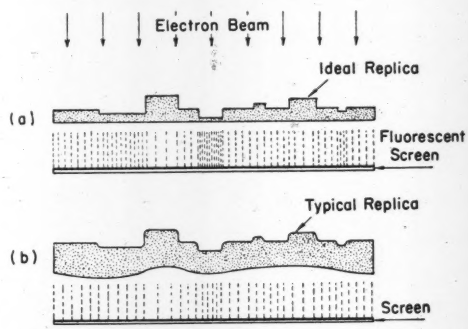
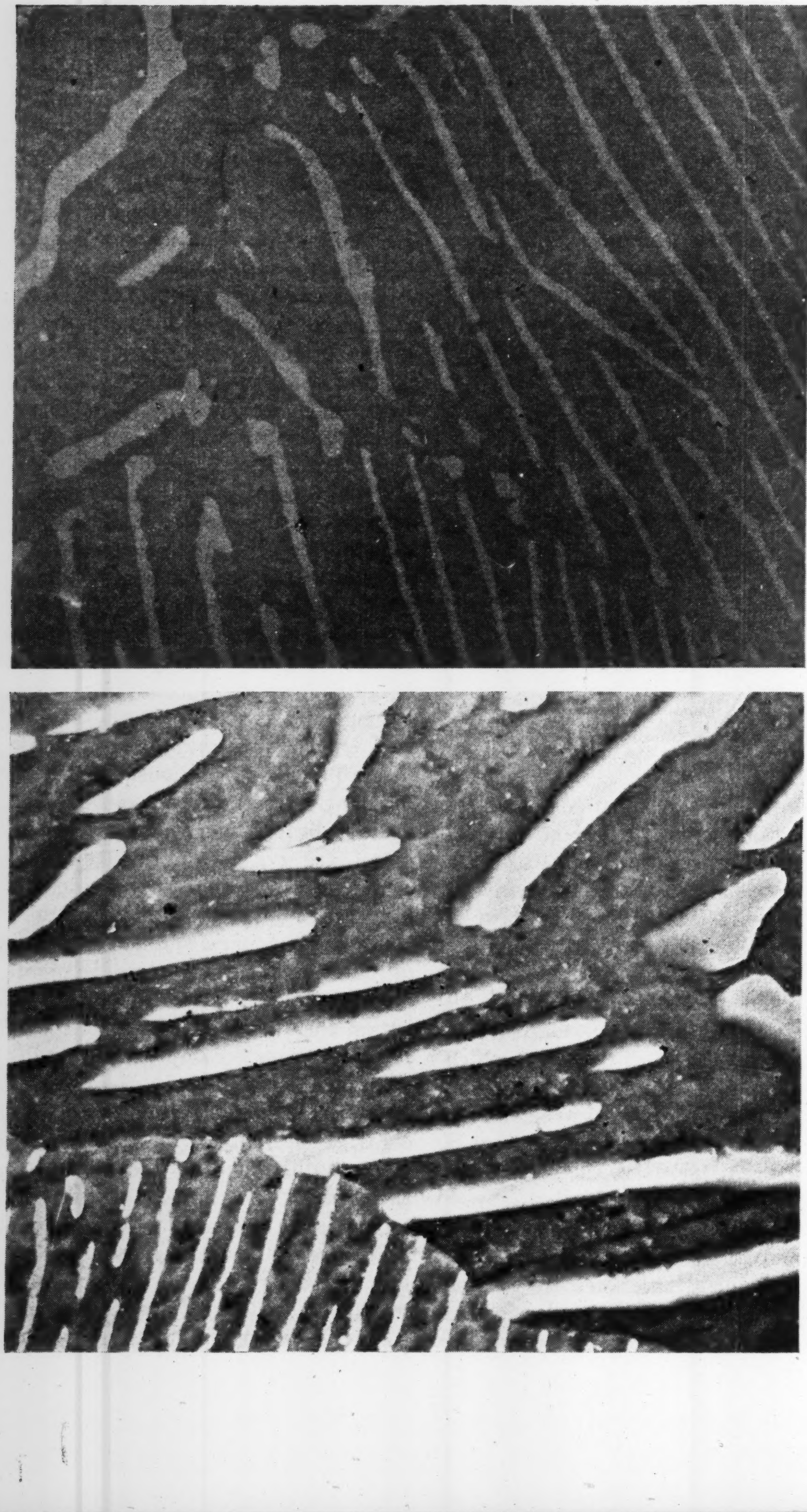


FIG. 2.—Contrast in Ideal and in Typical Replicas.

Plastic replicas are most conveniently made by casting the replica on the prepared metal surface from a dilute solution of a suitable plastic in a volatile solvent (for example, a 0.5 per cent solution of Formvar in dioxane). An idealized cross-section of such a replica after being cast on an etched metal surface is shown diagrammatically in Fig. 1 (*a*). One surface of the replica is flat while the other, which is in contact with the specimen surface, follows the contour of the local elevations and depressions. The stripped replica is shown in Fig. 1 (*b*). Here the replica has been turned over so that the "structure" side is uppermost. It can be seen that the surface elevations and depressions of the original specimen have been transferred as thickness variations in the plastic film.

When this replica is placed in the microscope and illuminated by an electron beam from a direction normal to the plane of the replica, the various thicknesses will cause local differences in the amount of scattering the electrons experience in passing through the replica. Consequently, there will be local differences in the electron intensity reaching the fluorescent screen as shown in Fig. 2 (*a*) by the dotted lines. The high spots or the constituents in relief which reproduce as thin areas in the replica will appear bright on the screen (where the electron density is highest), whereas the depressions, or constituents in intaglio, which reproduce as thick areas will appear dark. Hence, the brightness of a particular point in the final image is a measure of the elevation of the corresponding point on the original specimen relative to the surrounding terrain.

The replica shown in Fig. 2 (*a*) is somewhat idealized and in practice such an ideal plastic replica is not generally obtained. More often than not, a replica having a cross-section more nearly like that shown diagrammatically in Fig. 2 (*b*) results. This is obviously considerably different from the ideal one. Unlike the ideal replica, the edges of the reproduced detail are not sharp but tend to be rounded. Furthermore, the side of the replica film opposite the "structure" side is not flat but tends to follow the contour of the original surface—especially for the larger detail. The most obvious difference is that the average thickness of the usual replica is considerably greater than the average thickness of an ideal one. This greater thickness results in a decrease in contrast in the final image, because the relative difference in thickness between the thickest and thinnest portions of the replica is not sufficient to cause a marked difference in the electron intensity reaching the screen. This is shown diagrammatically in Fig. 2 (*b*). Because of this lack of contrast, the differences in eleva-



(*a*) Ideal (thin) replica.

(*b*) Typical replica.

FIG. 3.—Comparison of Contrast in Thin and Typical Replicas of Coarse Pearlite (×7500).

tion of the original specimen surfaces are not clearly delineated. The contrast of a micrograph obtained from a more or less ideal replica as compared with that of a micrograph obtained from a thick replica is shown in Fig. 3. These are micrographs of a coarse lamellar pearlitic structure in plain carbon steel. The decrease in contrast between the light cementite lamellae and the darker ferrite matrix upon increasing the replica thickness is distinctly manifest by these micrographs.

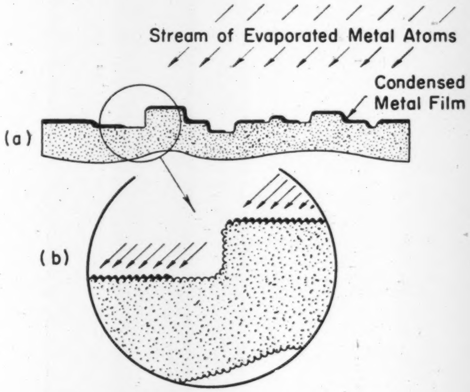


FIG. 4.—Shadow-Cast Plastic Replica.

Fortunately, the electron microscopist has been able to overcome the problem of poor contrast in plastic replicas by a technique known as "shadow-casting." Shadow-casting is essentially an operation whereby a thin film of a dense metal is deposited at an oblique angle upon the replica surface as shown schematically in Fig. 4 (*a*). The operation is accomplished by evaporating the dense metal from an incandescent filament in a high vacuum chamber and allowing the vaporized metal atoms to condense upon the replica surface. Since the metal atoms approach the replica surface from an oblique angle and stick where they strike, certain areas of the irregular replica surface will receive no metal because of the shading effect of adjacent projecting detail on the "windward" side.

When the shadow-cast replica is illuminated in the microscope from a direction normal to its surface, the areas which received no metal will transmit electrons as before whereas the metal-coated areas will cause increased scattering. Hence, shadow-casting results in an effective increase of contrast in the plastic replica. Shadow-casting derives its name from the fact that electron micrographs of replicas or other specimens processed in this manner, if printed so that the areas which received no metal are dark, appear as though the specimen were being illuminated obliquely with visible light and the surface projections are causing shadows on adjacent plateaus or depressions.

Besides increasing contrast, shadow-casting is beneficial from other standpoints. It makes possible, knowing the angle of shadow, the measurement of surface elevations by measuring the length of the shadow, and also imparts a third dimensional effect which is often pleasing from the appearance standpoint. Figure 5 is an electron micrograph of a Formvar replica shadowed with chromium. The subject is coarse lamellar pearlite in eutectoid plain carbon steel. In this case the replica was shadowed at a rather high angle (45 deg). The micrograph has also been printed so that thin areas in the replica (which represent the cementite) are lightest in tone. Consequently, the shadows are also light and, because of the high angle of shadow, appear as a very narrow "high-light" along the upper edge of the cementite lamellae. High-angle shadowing subdues the third-dimensional effect but still promotes an increase in contrast.

Although the problem of poor contrast in plastic replicas can be overcome by shadow-casting, a new one arises. The plastics, used for making replicas in general, possess an internal structure which is large enough to be resolved by the electron microscope. This structure gives rise to a surface texture, shown in Fig. 4 (*b*). Ordinarily this surface texture is invisible because of lack of contrast, but when shadow-cast the inherent granularity of the replica surface can be seen. Granularity due to plastic structure in replicas is illustrated in the electron micrographs of Fig. 6. Figure 6 (*a*) shows cementite in a matrix of ferrite while Fig. 6 (*b*) shows retained austenite in a martensite matrix. The microconstituent in relief in both micrographs (the cementite and retained austenite) exhibits a granular surface appearance. This is rather convincing evidence that the structure observed is a replica artifact rather than true structure, since it is quite improbable that two such widely different microconstituents should exhibit exactly the same structure of this order of magnitude. That the granularity is due to the plastic structure may be further substantiated by the examination of shadow-cast plastic films cast on water. From an examination of the micrographs of Fig. 6, it can be seen that any structure in metal specimens of the same order of size or smaller than the plastic granularity, even though it were reproduced faithfully, would be completely obliterated by the structure of the replica itself. Consequently, the limit of resolution of shadow-cast plastic replicas is determined by the size of the structure of the particular plastic used. For the plastics generally used for making replicas, this limit lies in the neighborhood of 100 to 200 Å. It is, therefore, apparent that the simple, direct-stripped plastic

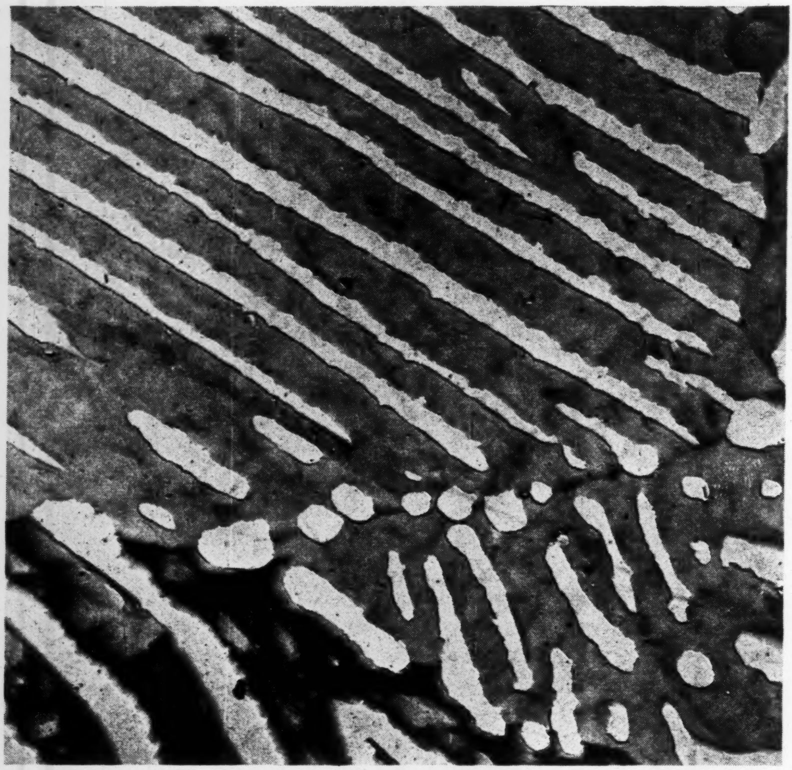
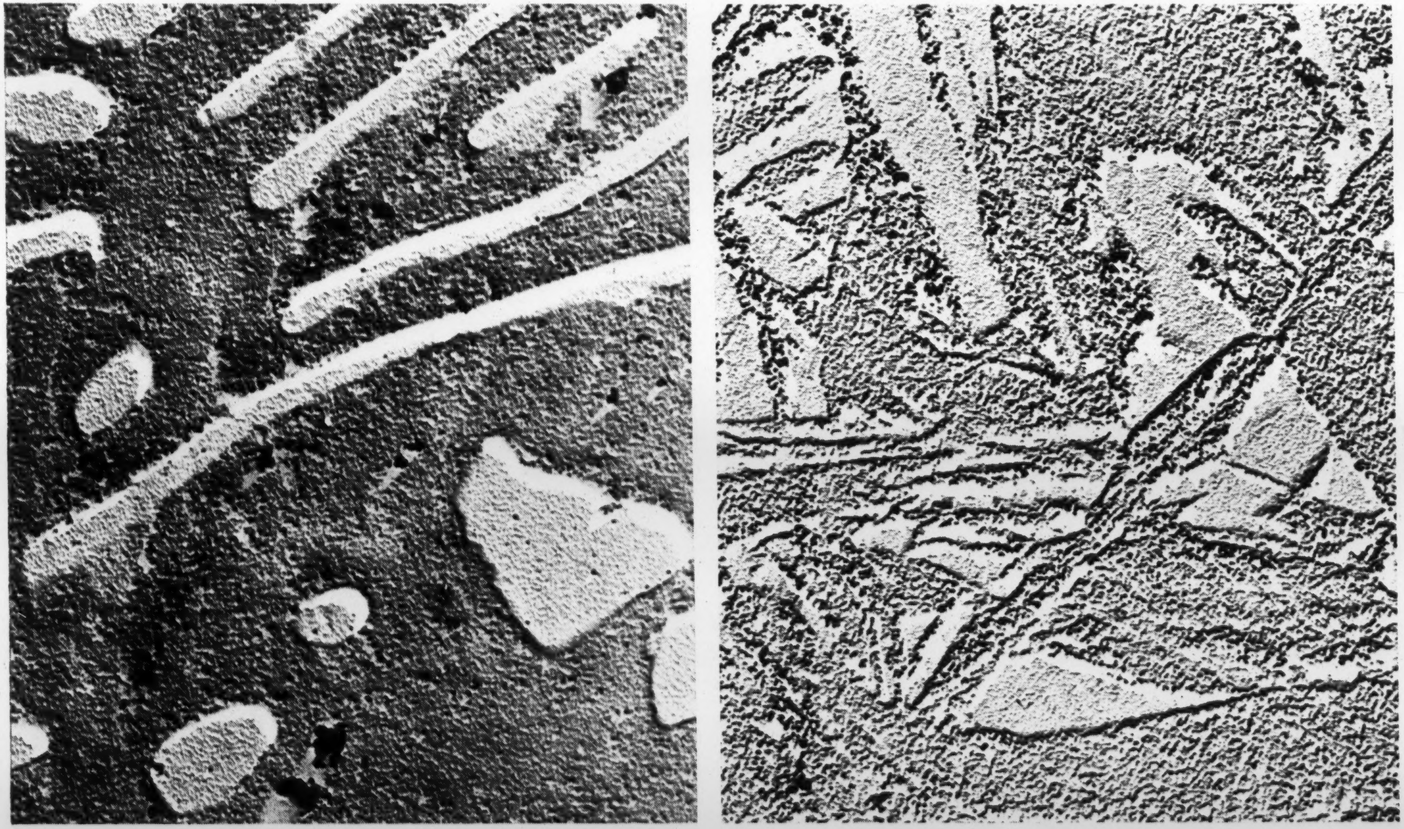


FIG. 5.—Shadow-Cast Plastic Replica of Coarse Pearlite (×7500).



(*a*) Cementite in ferrite. (*b*) Retained austenite and martensite.

FIG. 6.—Shadow-Cast Plastic Replicas Showing Granularity Due to Plastic Structure (×15,000).

replica is unsatisfactory for the examination of structure smaller than 200 Å.

This same sort of problem was encountered in the electron microscopy of extremely small particles—for example, virus particles or large organic molecules which are of approximately the same size as the structure found in plastics. When these very small particles are deposited on a plastic supporting film and shadow-cast, they are lost in the granular structure of the film. To overcome the difficulty, Williams and Wyckoff (2) devised a "pre-shadowing" technique. This technique is essentially as follows:

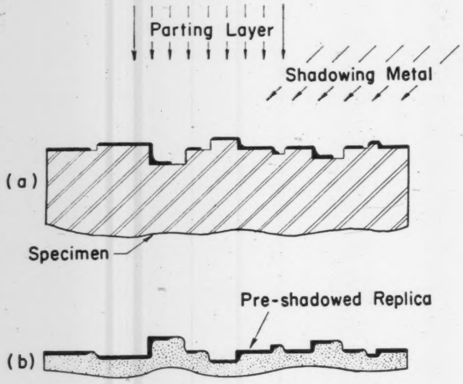


FIG. 7.—Pre-shadowed Plastic Replica.

Instead of depositing the particles on a plastic film and shadow-casting both, the particles are deposited on a more structureless surface—the surface of a clean polished glass, for example—and shadowed. The shadowed particles are then mounted for electron microscopy by casting a film of a suitable plastic over the shadowing metal film and stripping both the particles and metal film together from the glass surface. This results in a preparation consisting of shadowed particles on an unshadowed plastic substrate. Since the plastic structure is unshadowed, it cannot be seen and therefore does not interfere with the examination of the particles.

Obviously, the same technique could be applied to overcome the objectionable granular structure of shadow-cast plastic replicas of metal specimens. Instead of shadowing the stripped plastic replica, it is possible to shadow-cast the original specimen as shown schematically in Fig. 7 (*a*). After the specimen has been shadow-cast, the plastic replica can then be cast over the shadowing metal layer and both stripped from the specimen together. This would result in precisely the same type of replica as obtained when small particle specimens are pre-shadowed—shadowed specimen detail upon an unshadowed plastic substrate, as shown in Fig. 7 (*b*). Being unshadowed, the granular texture of the plastic is not seen because of lack of contrast.

Besides suppressing the granular plastic structure, pre-shadowed replicas should show an improvement in resolution over that of shadowed plastic replicas. This is because that part of the replica which was in contact with the specimen and, therefore, actually reproduces the detail (Fig. 7 (*b*)) is made of metal, a material which has a smaller intrinsic structure than plastic and therefore capable of reproducing fine detail more faithfully.

The idea of pre-shadowed replicas is sound in principle but, unfortunately, it is considerably more difficult to strip thin evaporated metal films from etched metal surfaces than it is to strip them from clean, smooth glass surfaces.

Pre-shadowed replicas as well as all-metal replicas have been suggested (1,2), but their application has been limited chiefly because of the difficulties encountered in stripping and handling the fragile metal films. Heretofore, it has been necessary to destroy the original specimen by dissolution in acid in order to free the metal replica. Williams and Wyckoff (2) suggested the use of an acid or water-soluble parting layer such as copper or sodium chloride to overcome this difficulty but found that this type of parting layer definitely limited the overall resolution of the replica technique. Since we first began an investigation of the possibilities of the electron microscope in metallographic studies at the Research Laboratories Division of General Motors, we have been interested in finding a simple, satisfactory means for preparing pre-shadowed plastic or all-metal replicas. Certainly this type of replica technique appeared to be the best, provided a satisfactory means could be devised for stripping the metal replica without destroying the specimen. Most of our work along these lines had been directed toward finding a suitable surface-active agent which could be used as a parting layer without affecting the resolution appreciably. Many substances of this type, chiefly those which are known to form monomolecular layers, were tried, but none of the early attempts were successful. We now attribute these failures to the fact that, of the several methods used to apply the materials, none was satisfactory. It is quite probable that some of these materials, if applied in the manner to be described, would now prove to be satisfactory.

TABLE I.—STEPS IN THE PREPARATION OF REPLICAS.

Shadowed Plastic	Pre-Shadowed Plastic
1. Polish and etch	1. Polish and etch
2. Cast replica	2. Apply parting layer
3. Back replica	3. Shadow-cast specimen
4. Strip replica	4. Cast replica
5. Mount on screen	5. Back replica
6. Remove backing	6. Strip replica
7. Shadow-cast replica	7. Mount on screen
	8. Remove backing

The key to the successful application of a surface-active agent was furnished in a private communication with Mr. V. G. Peck of the Tennessee Eastman Corp. The method he suggested, and previously reported by Kaye (3), is to apply the surface-active agent by vacuum evaporation. Kaye and Peck have more recently used this method in the preparation of aluminum–beryllium replicas of cellulose acetate fibers (4). Using this method for applying the surface-active parting layer, we have found that pre-shadowed plastic or metal replicas can be stripped from etched metal surfaces with comparative ease and without destroying the specimen.

The essential steps of the complete technique as compared with the steps used in present practice for the preparation of shadowed plastic replicas are shown in Table I. It will be noted that the new technique for pre-shadowed replicas is essentially the same as that for preparing shadowed plastic replicas except for the addition of one more step and a reshuffling of the sequence. The addition of another step does not, in this case, introduce further complications into the replica process since the parting layer (the new step) is applied in the same vacuum chamber and immediately prior to the evaporation of the shadowing metal. To apply the surface-active parting layer ("Victawet" 35B, Victor Chemical Works, Chicago, Ill.), a pellet of the dried material weighing 0.5 to 1 mg is placed in a 20-mil conical tungsten filament and evaporated from a direction normal to the plane of the specimen surface as shown schematically in Fig. 7 (*a*). The filament to specimen distance is 4 to 5 cm. The evaporation of the Victawet must be performed slowly. If the filament is heated too rapidly before the final traces of water are driven off, the pellet will jump out of the basket before it melts and begins to evaporate. The current needed to evaporate Victawet 35B from a 20-mil filament is 2 to 3 amp. With this amount of current flowing, the temperature of the tungsten filament is still below a dull red heat.

After the evaporation of the surface

active material is complete, the filament current is increased to 20 to 25 amp to heat the filament to incandescence for a period of 1 to 2 sec. The hot filament "heat treats" the freshly deposited parting layer. According to Kaye (3), this "heat treatment" orients the molecules of the Victawet.

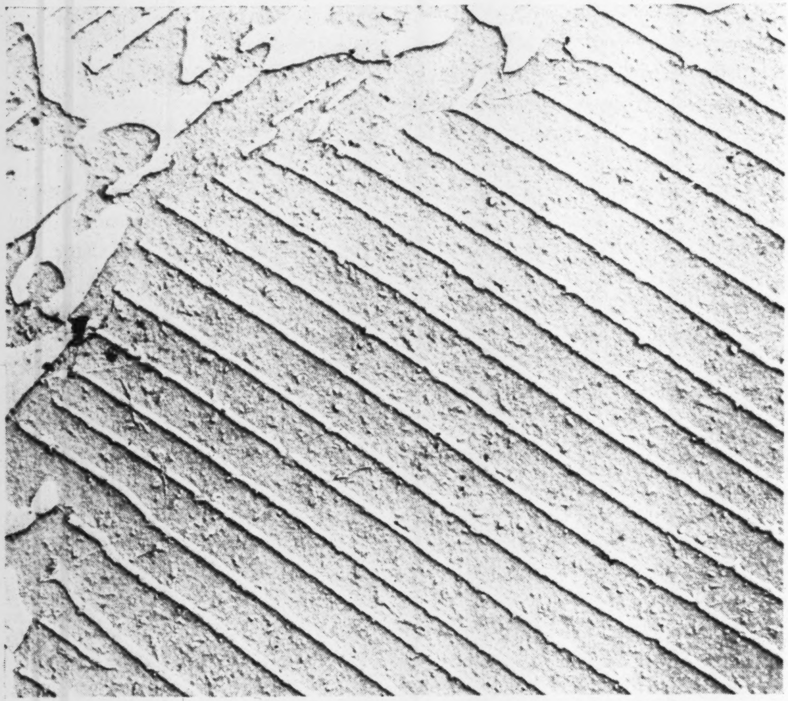


FIG. 8.—Pre-shadowed Plastic Replica of Coarse Pearlite (×7500).

The deposition of the parting layer is followed immediately, without breaking the vacuum, by evaporation of the shadowing metal from another filament. The shadowing metal used in the present work is chromium, previously plated upon and evaporated from the tip of a 12-mil tungsten hairpin filament.

When the pre-shadowed specimen is removed from the vacuum chamber, a Formvar replica is cast upon the surface immediately in the usual way using a 0.5 per cent solution of Formvar in dioxane. After the plastic replica has dried it is backed, stripped, and mounted, using methods previously described by the authors (5).

It should be pointed out at this time that it is not always necessary to back the pre-shadowed Formvar replicas to obtain good results. Entirely satisfactory replicas can be made without the use of a backing layer, in which case two steps are subtracted from the number of operations required to make pre-shadowed plastic replicas. The extra time and effort expended in backing the replicas, however, is well worth while because backed replicas are much more easily handled and manipulated during the stripping and mounting operations. Backing also insures a complete, strain-free replica of the entire prepared surface of the specimen with each attempt.

Although it is possible to "dry-strip" the pre-shadowed replicas using the scotch-tape method, we feel that the wet-stripping method (5) is best and that, in order to obtain completely satisfactory results, it is essential. Dry-stripped, pre-shadowed plastic replicas exhibit the objectionable strain marks often found in dry-stripped, unshadowed plastic replicas.

The improved resolution, absence of plastic granularity, and other desirable features of pre-shadowed replicas are illustrated by the micrographs in Figs. 8, 9, 10, and 11. These are pre-shadowed replicas of some of the familiar microstructures found in plain carbon eutectoid steel. These microstructures were chosen as subjects for the initial work with direct-stripped, pre-shadowed replicas because we already had considerable experience in the study of them using the

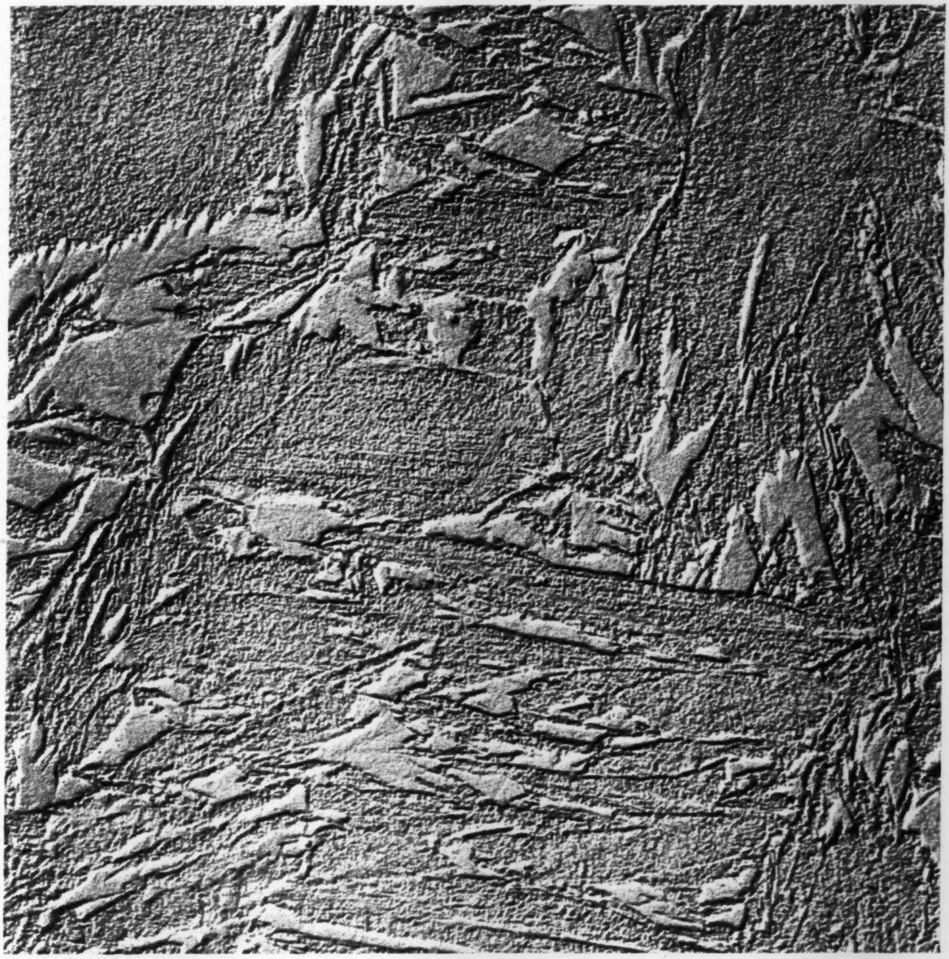


FIG. 9.—Pre-shadowed Plastic Replica of Martensite and Retained Austenite (×12,000)

customary shadowed plastic replica technique. Hence, the results obtained using pre-shadowed replicas could be compared directly with those obtained with an established method of proven reliability on the same microstructures.

FIG. 10.—Bainite Isothermally Transformed at 500 F. Pre-shadowed Formvar Replica (×12,000).

Figure 8 is an electron micrograph of coarse pearlite. It can be seen that there is no plastic granularity visible on the nonetching cementite (light phase). This micrograph also illustrates another indirect advantage of pre-shadowed replicas. An objection frequently raised concerning electron micrographs of pearlite is that the micrographs generally show a greater proportion of cementite than is theoretically possible. The reason for this has always been attributed to overetching which uncovers the sides of cementite lamellae which do not lie perpendicular to the plane of polish. Pre-shadowed replicas make it possible to use lighter etches since, because of their superior resolution, smaller differences in surface elevations can be reproduced faithfully. These lighter etches yield micrographs which exhibit a ferrite to cementite ratio nearer the true value. In the lamellar portion of the micrograph of Fig. 8, where the cementite plates are nearly perpendicular to the plane of polish, the ferrite to cementite ratio is approximately 5.5 to 1.

Figure 9 is a pre-shadowed replica of the "as-quenched" structure of plain carbon eutectoid steel showing martensite and retained austenite. The martensite needles exhibit an extremely minute regular structure that is resolved only occasionally by shadowed plastic replicas, and no plastic granularity is visible on the unetched retained austenite.

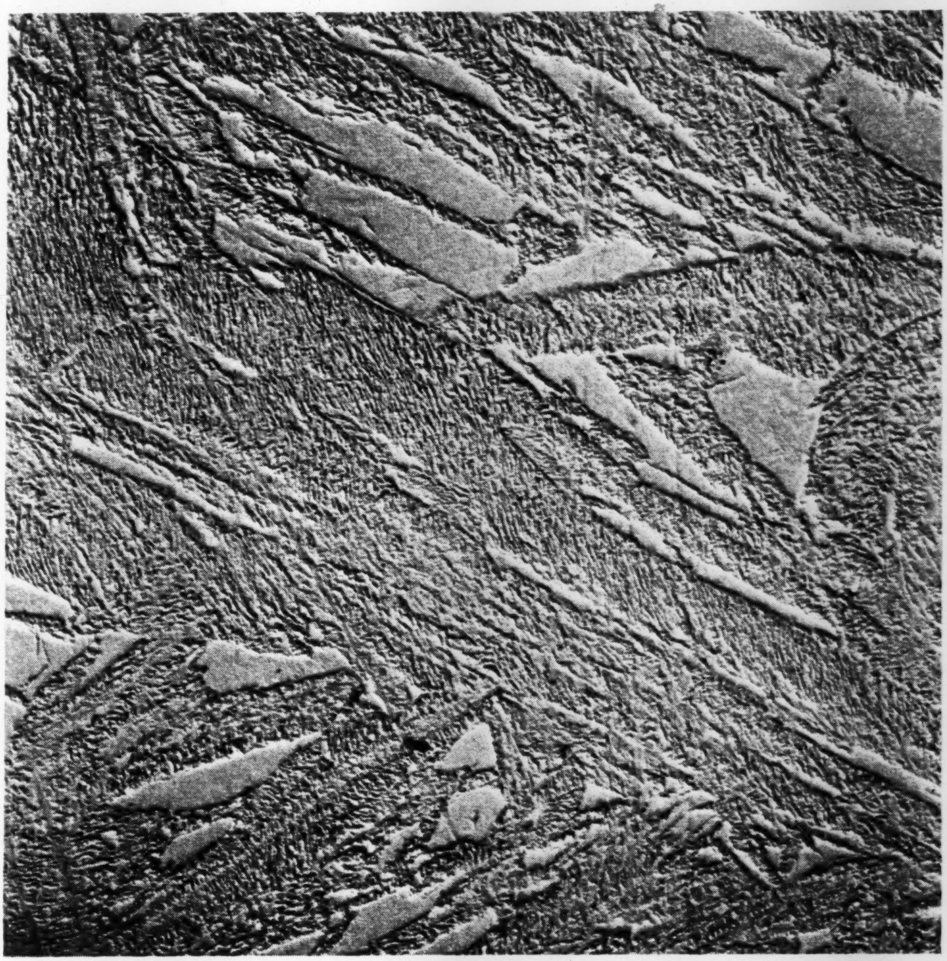


FIG. 11.—Martensite Tempered at 400 F for 1 hr. Pre-shadowed Formvar Replica (×12,000).

Figure 10 is a micrograph of lower bainite formed upon isothermal transformation at 500 F. The characteristic cross-striated needles of bainite are clearly shown. Pre-shadowed replicas of lower bainite exhibit a greater amount of carbide than do shadowed plastic replicas. We attribute this to the fact that the pre-shadowed replicas, because of their superior resolution, reproduce the extremely small carbide particles which the shadowed plastic replicas cannot resolve. Figure 11 is an electron micrograph of a martensitic structure after having been tempered at 400 F for 1 hr. This micrograph also illustrates the advantage of better replica resolution. Heretofore, we have been unable to etch this specimen so that the fine structure of the martensite and the retained austenite are clearly shown in the same micrograph. Etches which were of the correct depth to develop the fine structure of the martensite were too shallow to develop the retained austenite, whereas etches deep enough to develop the retained austenite overetched the martensite. In the present case the specimen has been etched just deeply enough to develop the fine structure of the martensite. At the same time the pre-shadowed replica has been able to detect the slight difference in elevation between the martensite and austenite phases so that the angular patches of retained austenite can be seen even with the light etch.

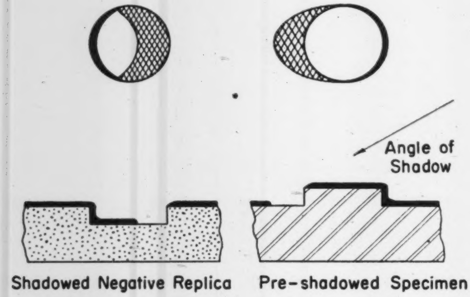
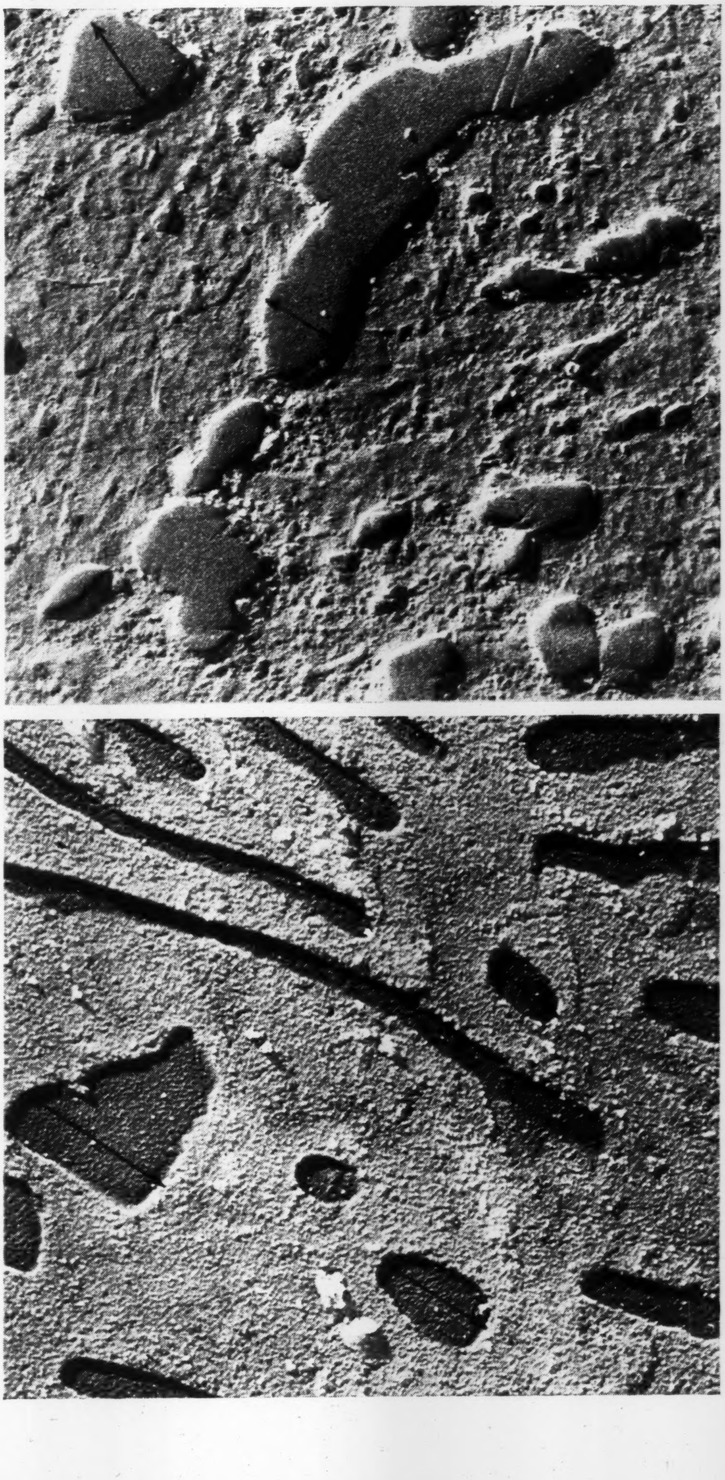


FIG. 12.—Position of Shadow for Two Types of Replica.

There is a fundamental difference between pre-shadowed and shadowed plastic replicas in regard to the interpretation of the resulting micrographs. Although one must be aware of this difference at all times, it becomes especially important when the micrographs are used for quantitative measurements. The difference between the two types of replicas involves the relative position of the shadow with respect to the detail which causes the shadow.

Consider, for example, a circular elevation on a specimen such as a sectioned cementite particle projecting from a ferrite matrix. When this projecting carbide particle is replicated in plastic, it will reproduce as a depression as shown diagrammatically at the left in Fig. 12. When this depression in the plastic replica is shadowed from the direction indicated, the shadow (that portion of the replica which receives no metal) as well as the shadow cap (that part of shadowing metal layer which builds up against the vertical wall of the depression opposite the shadow) both lie *inside* the boundary of the carbide. Hence, when this carbide is measured on the final electron micrograph, the measurement should be made from outside edge of shadow to outside edge of shadow-cap to obtain the true diameter of the particle. For pre-shadowed replicas, where the original projecting carbide is shadowed as shown at the right in Fig. 12, both the shadow and shadow-cap lie *outside* the boundary of the carbide and therefore, in order to obtain the true diameter, the measurement should be made from inside edge of shadow to inside edge of shadow-cap.

Figure 13 shows electron micrographs of both shadowed plastic and pre-shadowed replicas of carbide particles in a ferrite matrix. The micrographs in this case have been reverse printed so that the "shadows" appear dark. The dimension arrow shown on each micrograph indicates the correct measurement of the



(*a*) Shadowed negative replica. (*b*) Pre-shadowed replica.

FIG. 13.—Position of Shadow for Two Types of Replica. Arrows indicate correct measurement to obtain true size of the carbide.

diameter of the carbide particles for that particular type of replica.

Needless to say, there are some potential difficulties which may be encountered in making pre-shadowed replicas. We have considered the possibility that the structure of the parting layer might seriously limit the resolution. However, in all cases where we have noticed a granularity in pre-shadowed replicas which might be attributed to parting layer structure, it has always been much smaller than the granularity due to plastic structure.

A difficulty which arises when the etch is deep and the shadow angle is low is illustrated in Fig. 14. Under these conditions the shadow is quite wide and results in a sizeable "hole" in the metal shadowing film. When the replica is cast and stripped, the plastic film, which is exceptionally thin at these points, sometimes tears along one side of the shadow leaving a hole through the replica. These

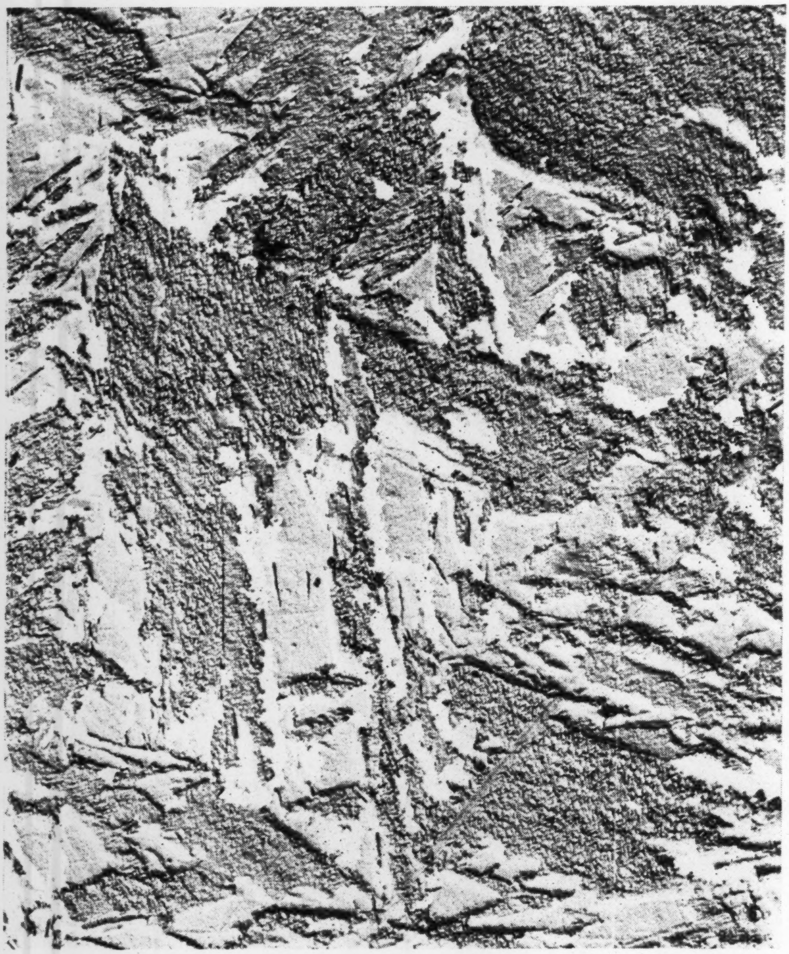


FIG. 14.—Pre-shadowed Formvar Replica. Shows tears which develop when etch is deep and shadow angle is low (×12,000).

torn places in the replicas are shown clearly in Fig. 14.

The difficulty just described seldom occurs when the etch is light and the shadow angle is kept high (27 deg or more with respect to the plane of the specimen). When it is necessary to use deep etches and low shadowing angles, the difficulty can be overcome by reinforcing the metal shadow layer with a thin continuous film of aluminum–beryllium alloy evaporated from a direction normal to the plane of the specimen. This procedure results in a pre-shadowed, all-metal replica which also can be direct-stripped if slight modifications in the stripping and mounting technique are made.

Although pre-shadowed replicas are, in many respects, no more difficult to prepare, we do not expect that they will entirely replace the ordinary shadowed-plastic type so widely and successfully used in present practice. Rather, they should be particularly reserved for those cases where a resolution better than 200 Å is required.

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DISCUSSION

Mr. Alfred L. Ellis.[1]—Some published data on the subject of plastic granularity which we have had an opportunity to examine and confirm do not put plastic granularity at quite the same order of magnitude which is ascribed to it here.

Has plastic granularity been checked by a method which seems to me to be quite informative, by dispersing the plastic material on the surface of glass and then examining the plastic films obtained in this manner?

Films prepared in this way have a pebbly structure or what Mr. Grube has called plastic granularity and the dimensions of the individual structural elements are usually about 50 Å.

Since the intermediate coating gives a structure, it seems possible that not too great a reward is accomplished by this proposed technique.

Mr. R. M. Fisher.[2]—It is well known that the surface of an evaporated metal film is often smoother than the surface of the substrate below. Would this effect obscure any significant detail on the surface being replicated?

Mr. W. L. Grube (*author*).—In answer to Mr. Ellis, it is true that some investigators have determined the size of the structure in plastics used for replicas to be in the neighborhood of 50 Å. However, unless absolutely fresh solutions are used it is not uncommon to find that the size of this structure increases upward toward 100 Å. In my opinion, one could not expect to reproduce, faithfully, specimen detail of a size much less than twice the size of the replica structure. This would, therefore, place a practical limit on the resolution of plastic replicas of 100 to 200 Å, the figure used in this paper. Since much of the microstructure of interest in metals is of this order of magnitude, it is very desirable to be able to extend the resolution of replicas below this limit. This can be accomplished by using the pre-shadowing technique described, since pre-shadowed plastic replicas are actually plastic-backed metal replicas which, as shown by Calbick (1) possess better intrinsic resolution. Although the ultimate resolution of pre-shadowed replicas may be limited by the structure of the parting layer, in cases we have observed, structure which may be attributed to the parting layer has always been much smaller than plastic structure. For these reasons it appears worth while to use the pre-shadowing technique.

In answer to Mr. Fisher's question, the smoothing action of the evaporated metal shadowing film probably would not obscure any significant detail because smoothing would most likely occur when the evaporated metal atoms approach from a direction normal to the surface. When the metal atoms approach the surface obliquely, as they do in shadow-casting, little smoothing action would be expected. In fact, there is evidence that the reverse is true. Even if smoothing should occur, it becomes of less importance in pre-shadowed replicas because the specimen detail is actually reproduced by the shadowing metal film rather than by the plastic film cast over it. There may be some smoothing action by the parting layer which is evaporated normally. Unfortunately we do not, as yet, have any conclusive evidence that this is, or is not, true. However, as shown by the illustrations in the paper, the parting layer does not obscure as much specimen detail as plastic granularity does.

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[2] Research Laboratory, United States Steel Co., Kearny, N. J.

APPENDIX III

ELECTRON-DIFFRACTION STUDY OF IRON CARBIDES IN BAINITE AND TEMPERED MARTENSITE

By A. E. Austin[1] and C. M. Schwartz[1]

Synopsis

Samples of bainite and tempered martensite, etched to leave the carbide phases in relief, have been examined by electron diffraction. The specimens were those used in the electron-microscope study of steel by Subcommittee XI on Electron Microstructure of Steel of ASTM Committee E-4 on Metallography. The steel was essentially plain carbon, of eutectoid composition. Cementite was found in samples isothermally transformed or quenched and tempered at or above 500 F. Both cementite and epsilon iron carbide exist at 500 F. In martensite tempered at 400 F, only epsilon iron carbide was found.

This paper presents the results of electron-diffraction examination of the carbide phases in 0.87 per cent carbon steel, isothermally transformed to bainite, or quenched and tempered. The work was undertaken as a supplement to that of Subcommittee XI of ASTM Committee E-4.

In the first Progress Report (**1**)[2] of this committee, the electron micrographs revealed a marked similarity among the microstructures of bainites and of tempered martensites. More recent investigation has shown a distinct difference between upper and lower bainite; these results appear in the committee's second Progress Report (**2**). The electron-microscope evidence of a variation in bainite structure and of a structural similarity to tempered martensite raised the question of possible phase differences in the transformation products. This question has been investigated by reflection electron-diffraction examination of the same specimens of Subcommittee XI which were used for microscopical study in this laboratory. The method has the advantage that the phases left in relief by the etchant may be detected, by proper choice of etchant, to the exclusion of the fast-etching constituents.

Experimental Work and Results

The steel was an essentially plain carbon steel of eutectoid composition. Specimens isothermally transformed to bainite or quenched and tempered were selected from those used by Subcommittee XI (**1**, **2**). Heat treatments and structures are noted in Table I; the specimen designations are those of the subcommittee. All specimens were polished as for electron microscopy, rinsed with alcohol after etching, and immediately evacuated in the electron-diffraction camera. The specimens were etched by either picral, nital, or trichloroacetic acid, since these etchants leave the desired microstructure in relief. The results

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[1] Battelle Memorial Institute, Columbus, Ohio.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 595.

TABLE I.—ELECTRON-DIFFRACTION IDENTIFICATION OF THE PHASES ETCHED IN RELIEF IN STEEL SPECIMENS.

Specimen	Heat Treatment[a]	Structure	Phase Identification
No. 4	6 sec at 550 F 7 min at 750 F	750 F bainite	Cementite
No. 16	6 sec at 550 F 9 min at 700 F	700 F bainite	Cementite
No. 15	6 sec at 550 F 15 min at 650 F	650 F bainite	Cementite
No. 14	6 sec at 550 F 30 min at 600 F	600 F bainite	Cementite
No. 13	1 hr at 550 F	550 F bainite	Cementite
No. 12	15 min at 500 F	500 F bainite, partial transformation	Cementite, epsilon iron carbide[b]
No. 5	2½ hr at 500 F	500 F bainite	Cementite, epsilon iron carbide
No. 7	brine quenched, tempered 1 hr at 400 F	400 F tempered martensite	Epsilon iron carbide
No. 20	brine quenched, tempered 1 hr at 500 F	500 F tempered martensite	Epsilon iron carbide, cementite
No. 8	brine quenched, tempered 1 hr at 600 F	600 F tempered martensite	Cementite
No. 9	brine quenched, tempered 1 hr at 800 F	800 F tempered martensite	Cementite

[a] All specimens were austenitized at 1800 F for 35 min.
[b] The evidence is questionable for positive identification of epsilon iron carbide in this specimen.

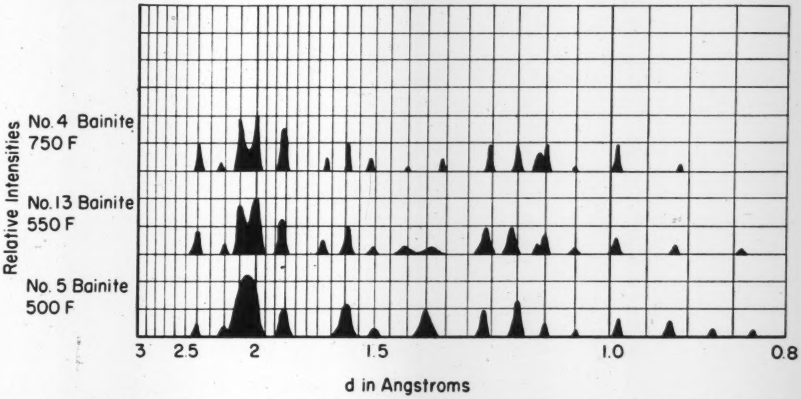

FIG. 1.—Graphical Representation of Electron-Diffraction Data of Etched Bainite Samples.

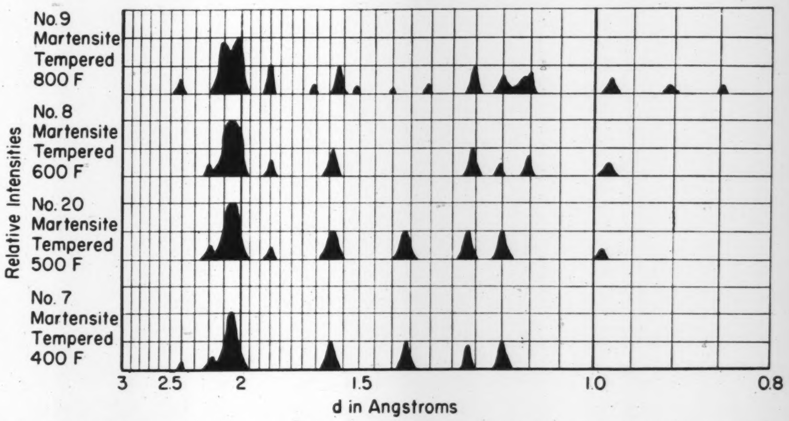

FIG. 2.—Graphical Representation of Electron-Diffraction Data of Etched Tempered Martensite Samples.

are summarized in Table I and in Figs. 1 and 2. The latter are graphical representations of the spacing, intensity, and shape of the diffraction rings of the patterns, based on visual estimation. In the case of cementite, all the lines observed in its complex X-ray diffraction pattern are not resolved in the electron-diffraction patterns. For comparison, the X-ray diffraction data (3) for cementite and hexagonal epsilon iron carbide are plotted in Fig. 3. The occurrence of the hexagonal epsilon iron carbide in low-temperature tempered martensite agrees with the data of Jack (4).

However, comparison of the pattern from specimen 4, 750 F bainite, with the X-ray pattern shows reasonable agreement, and the phase in relief is clearly cementite. The line broadening increases as the transformation temperature is reduced, as shown, for example, in the plot of specimen 7, 400 F tempered martensite. This pattern is in good agreement with that reported by Jack (4) for the hexagonal carbide, with no evidence for cementite. The identification of the hexagonal iron carbide in specimen 5, 500 F bainite, and specimen 20, 500 F tempered martensite, is based upon a comparison of their respective patterns with those of specimens 4 and 7.

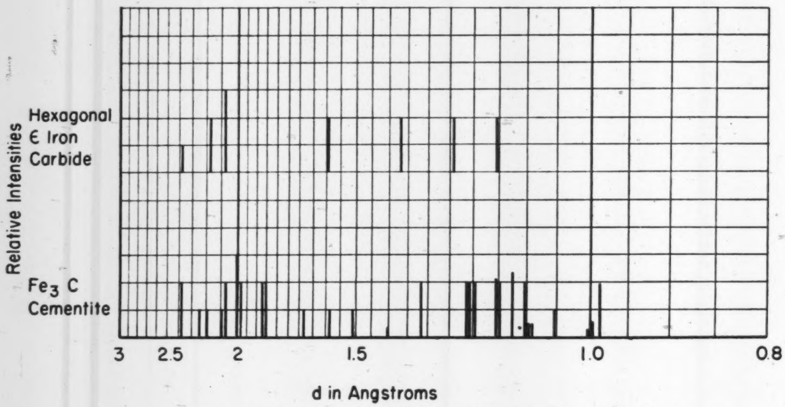

FIG. 3.—Graphical Representation of X-Ray-Diffraction Data.

DISCUSSION OF RESULTS

Closely spaced diffraction lines are not as well resolved in reflection electron-diffraction patterns as in the case of X-ray diffraction, for reasons such as geometrical limitations involving the short wavelength radiation employed, and the uncertainty of the specimen-to-plate distance. In addition, in the case of these specimens, the diffraction lines are broadened, probably by local inhomogeneities or microstrains resulting from rejection of transformation products from the matrix.

In the case of the partially transformed 500 F bainite, specimen 12, cementite is present. There is only meager evidence for the presence of the hexagonal carbide, although in specimen 5, fully transformed at the same temperature, the hexagonal phase is definitely observed. This suggests that cementite is the first phase to precipitate, during isothermal transformation at 500 F. However, insufficient work has been done with this specimen to be certain that representative fields have been sampled, and the above suggestion must be regarded as tentative.

The work of Hofer and Cohn (5) on highly carburized iron showed, from magnetic analysis, that hexagonal iron carbide decomposes above 465 F to form Hagg percarbide. However, Hagg percarbide was not found in the present investigation, and, in the eutectoid steel, the upper temperature of stability of the hexagonal carbide is about 500 F. The work here agrees in part with the magnetic analysis by Crangle and Suchsmith (6) on tempering of martensite and retained austenite in iron with 1.7 per cent carbon. They reported hexagonal epsilon iron carbide as the first transformation phase, while the second transformation started above 485 F. They reported that the second transformation phase may be Hagg percarbide according to the magnetic data.

CONCLUSIONS

The electron-diffraction data show that in bainite isothermally transformed and martensite tempered above 500 F the phase etched in relief is cementite. The 500 F bainite and tempered martensite samples have both cementite and the hexagonal epsilon iron carbide. The 400 F tempered martensite contains only the hexagonal epsilon iron carbide. These data confirm the work of Jack (4, 7) in that martensite decomposes, first to a close-packed hexagonal iron carbide and then to cementite.

Acknowledgment:

This work was supported jointly by the Timken Roller Bearing Co. and Battelle Memorial Inst.

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DISCUSSION

MR. RALPH T. BRANNAN.[1]—It has been stated that X-ray diffraction would give more resolution. Do the conclusions drawn here agree with X-ray diffraction, or has this been done?

MR. D. M. TEAGUE.[2]—Perhaps it might be pointed out that electron-diffraction here has a rather important advantage in that when the polished specimen was etched, the ferrite was attacked strongly, leaving the carbide platelets in relief.

Electrons have very low penetrating power so that the diffraction pattern obtained is of the carbide platelets in relief, and ferrite does not interfere in any way. Utilizing X-ray diffraction, the ferrite lines would interfere very strongly because the X-ray has a much stronger penetrating power. Electron diffraction is, therefore, a very neat way of eliminating the ferrite interference.

MR. C. M. SCHWARTZ (*author*).—We have not used X-ray diffraction to verify the existence of the Jack carbide in these particular specimens. By the term resolving power, I referred to the separation of closely spaced diffraction lines in a complex pattern such as that of cementite. An X-ray diffraction pattern of, say, coarsely crystalline extracted carbides would show better resolution of the lines than is possible in the conventional electron diffraction camera.

The Jack carbide yields a simple pattern, but, as the slide showed, the diffraction lines were quite broad. The material is obviously very fine grained, and it would be difficult to detect in these samples by X-ray diffraction because of line broadening. In this respect, therefore, electron diffraction is superior to X-ray diffraction, because of its ability to yield a diffraction pattern from a phase too fine-grained to give an X-ray diffraction pattern.

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[2] Assistant Head of Chemical Research, Chrysler Corp., Detroit, Mich.

REPORT OF COMMITTEE E-5
ON
FIRE TESTS OF MATERIALS AND CONSTRUCTION*

Committee E-5 held one meeting during the past year in Cleveland, Ohio, on March 6, 1952. Meetings of subcommittees preceded this meeting.

The committee now consists of 54 members, of whom 24 are classified as producers, 7 as consumers, 19 as general interest members, and 4 as consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. L. Brown.
Vice-Chairman, W. J. Krefeld.
Secretary, R. C. Corson.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends that the following revision of the Standard Methods of Fire Tests of Building Construction and Materials (**E 119 – 50**)[1] be approved for reference to letter ballot of the Society for immediate adoption, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society:[2]

Section 10.—Add the following:

> Wherever practical, material or construction shall be weighed at intervals during the period of drying and the weight on successive days recorded. Weighing shall be continued until the weight shall have remained essentially constant for not less than 5 successive days under favorable drying conditions of the open room of the laboratory, or two successive days if dried in a heated, air-conditioned chamber.
>
> If weighing of the total material or construction of the test specimen is impractical, a suitable sample designed to give an accurate estimate of the condition of the dryness of the completed sample shall be selected or fabricated and subjected to weighing and conditioning as specified above for the complete test specimen.

TENTATIVE REVISIONS CONTINUED

The committee recommends the continuation of the tentative revisions covering Sections 26 (*c*) and 27 to 30, inclusive, without change, of the Standard Methods of Fire Tests of Building Construction and Materials (**E 119 – 50**).[1]

TENTATIVE CONTINUED WITHOUT REVISION

The Committee recommends that the Tentative Method of Fire Hazard Classification of Building Materials (**E 84 – 50 T**) be continued as tentative pending possible revision resulting from research now being conducted upon smaller tunnel-type test equipment.

CONTINUATION OF STANDARD

The committee recommends that the Standard Methods of Fire Tests of Door Assemblies (**E 152 – 41**) be continued as standard, pending further study.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] 1950 Supplement to Book of ASTM Standards, Part 4.

[2] This recommendation was referred back to Committee E-5 for further consideration as a result of action at the Annual Meeting.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Fire Tests of Materials and Construction (G. N. Thompson, chairman).—The committee has been requested by building code writing bodies to include fire and hose stream test methods for constructions having fire resistance ratings less than one hour (E 119 - 50)[1]. This project has received very careful consideration as to the advisability of preparing such a method. Because of the wide use of ASTM Standards and the influence they have upon users of building materials, the committee is uncertain as to (*1*) the effect of publishing such a standard, (*2*) the value of the data to be obtained by the application of a hose stream to constructions having a fire resistance rating less than one hour, and (*3*) how such data is likely to be used. No consensus of opinion has been obtained and the entire subject of hose stream requirements is to be reviewed and restudied by the committee.

The inclusion in Standard E 119 of a fire test method using small size specimens as suggested by ASTM Committee E-6 is still receiving careful study. At present, efforts are being made to develop a recommended method for such exploratory tests which can be included as an appendix to the fire test method. This recommended method is being drafted to state the purpose and limitation of use, making reference to E 119 for all details of equipment and test procedure, and to outline how the test data are to be reported. Consideration is being given to the clarification of Paragraph 32 (*b*) of E 119 in the test of protection for combustible framing, or for combustible facings on the unexposed side of walls, partitions and floors with respect to members embedded on three sides in masonry, concrete or other noncombustible material.

Subcommittee IV on Fire Tests of Acoustical and Similar Finishes (N. D. Mitchell, chairman).—Very marked and encouraging progress has been made in investigating the possibility of using smaller size tunnel test specimens and equipment than specified in the Tentative Method of Fire Hazard Classification of Building Materials (E 84 - 50). Fire test equipment for this purpose has been developed and used for making a large number of tests of different types of material. The results obtained compare favorably with the results established on similar materials with the equipment outlined in E 84 - 50 T. Further tests are contemplated to obtain greater perfection in the control of draft conditions and observation of results.

Subcommittee V on Nomenclature and Definitions (J. R. Shank, chairman).—Efforts to define "noncombustibility" are continuing. Unless the definition as applied to materials is established in accordance with standardized performance conditions, it will not have the same meaning to all users. Performance standards in the form of a test procedure are, therefore, necessary. Progress has been made toward the development of such a test procedure. Several testing laboratories have conducted tests on various materials. The results have indicated that the tests so far used need to be limited to certain classes of materials and that further study is needed to develop separate tests for each group of materials which, by their nature, have characteristic differences in their behavior.

The scope statement of the committee is being reviewed for the purpose of stating more clearly the over-all activity of the committee, including a specific reference to indicate that the committee is to review all fire test specifications prepared by other ASTM Committees.

This report has been submitted to letter ballot of the committee, which consists of 49 voting members; 41 returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. L. BROWN,
Chairman.

R. C. CORSON,
Secretary.

REPORT OF COMMITTEE E-6
ON
METHODS OF TESTING BUILDING CONSTRUCTIONS*

Committee E-6 on Methods of Testing Building Constructions held no meetings during the past year but has carried on its activities by correspondence.

The committee consists of 56 members of whom 49 are voting members. The members are not classified. During the past year three individuals have been elected to membership: G. E. Strehan, L. V. Teesdale, and G. H. Wright. The committee regrets to report the death of three of its members: J. H. Courtney, who was Secretary of Committee E-6 since its inception in 1946 until his death in March 1951; F. E. Richart, the first chairman of Subcommittee III and First Vice-Chairman of the committee during 1948–50; and Dr. Albert London, who served as a consulting member to Subcommittee VII on Sound Transmission since 1948.

The loss of Mr. Courtney and his excellent secretarial services curtailed the proper handling and reporting of committee activities. However, the committee has been fortunate in getting R. A. Biggs to take over the duties of secretary.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. A. Liska.
Vice-Chairman, K. F. Weadt.
Secretary, R. A. Biggs.

Revision of Tentative, Adoption as Standard

The committee recommends that the Tentative Methods of Testing Truss Assemblies (E 73 – 48 T)[1] be approved for reference to letter ballot of the Society for adoption as standard with the following changes:

Section 6 (*d*).—Insert in the second sentence after the words "sufficient time" the statement "preferably about five minutes".

Section 7.—Delete the last sentence and substitute the following: "Both tension and compression chords shall be braced to simulate the lateral support provided in actual service and the bracing shall be applied to the ends of the truss as well as to intermediate points. The bracing shall be of the same general character as that described in Section 6".

The recommendation in this report has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Activities of Subcommittees

Subcommittee I on Panels for Light Building Construction (H. L. Whittemore, chairman).—The Standard Methods of Conducting Strength Tests of Panels for Building Construction (E 72) first issued by the Society in 1947 were completely revised in 1951, to include the latest testing methods and procedures which have been found desirable to evaluate the strength of housing components. Methods have been added to determine the tensile strength of walls and the strength of fastenings at the top and bottom of the walls, since it has been demonstrated that design wind loads caused tensile loads on walls to resist the uplift of the roof. Methods for evaluating properties of load-bearing partitions have also been added to this testing procedure.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 4.

[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee II on Connections and Assembled Structures (G. M. Rapp, chairman) held one meeting during 1951 and is preparing drafts of test methods for the strengths of joints in panel construction in tension, bending, and shear. The current interest in portable military shelters indicates that standard methods of evaluating joint performance should be promptly established.

Subcommittee III on Large Structural Units (E. C. Hartmann, chairman) during the year prepared a revision of the Tentative Methods of Testing Truss Assemblies (E 73 - 48 T) and has recommended its adoption as a standard.

Subcommittee IV on General Structural Elements (K. F. Wendt, chairman) is preparing a draft of Standard Methods of Test for Strength and Stiffness of Prefabricated Floor and Roof Constructions for Buildings, and plans to have the draft ready for discussion at the Annual Meeting.

Subcommittee V on Durability (E. C. Shuman, chairman) has under consideration the adoption of a "Test Hut" as a means for evaluating the durability of building materials. This will be further discussed at the Annual Meeting.

Subcommittee VI on Insulation (F. G. Hechler, chairman) is studying the problem of establishing a test procedure for water vapor transmission of building materials and constructions. Close liaison is being maintained with Committee C-16 in the development of test codes for heat transfer of structures under both laboratory and field conditions.

Subcommittee VII on Sound Transmission (R. K. Cook, chairman).—This subcommittee promulgated the present Tentative Recommended Practice for Measurement of Air-Borne Sound Transmission Loss E 90 - 50 T. It is believed that this procedure should be continued as tentative until it receives additional use and should be correlated with the procedures under development by an ASA group that is studying sound transmission loss measurements. The subcommittee has begun work on a tentative method for the measurement of sounds due to impact which are particularly important in building structures.

Subcommittee VIII on Fire Resistance (Harold Perrine, chairman) has been actively interested in obtaining the adoption of small panel or exploratory fire test methods for building constructions and materials. The committee has recommended that action be taken, but some correlation with other groups interested in fire tests has been found necessary. It is hoped that the necessary correlation can be completed in the near future for the procedure to provide for standardized testing methods for evaluating materials at a relatively low cost. Afterward such materials that show promise can be more completely studied in fire tests of full-size panels.

This report has been submitted to letter ballot of the committee, which consists of 49 voting members; 39 members returned their ballots, of whom 37 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. A. Liska,
Chairman.

R. A. Biggs,
Secretary.

REPORT OF COMMITTEE E-7

ON

NON-DESTRUCTIVE TESTING*

Committee E-7 on Non-Destructive Testing met at Atlantic City, N. J., on June 19, 1951 in conjunction with the Annual Meeting of the Society. Numerous Executive Council and subcommittee meetings have been held since.

The election of officers resulted in the reelection of the present incumbents for the ensuing term of two years.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Industrial Radiographic Terminology for Use in Radiographic Inspection of Castings and Weldments (E 52 – 49 T) be continued for one more year without revision.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Industrial Radiographic Standards for Steel Castings (E 71 – 47 T)[1] be approved for reference to letter ballot of the Society for adoption as standard without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Recommended Radiographic Practice (H. E. Seemann, chairman) submitted the Tentative Recommended Practice for Radiographic Testing to the committee and a letter ballot has recommended its publication. Submission to the Society has been delayed until editorial changes, suggested by the single negative vote, can be incorporated.

Subcommittee II on Comparison Radiographs of Welds (Alexander Gobus, chairman) has obtained sets of sample plates and radiographs of manual arc welds from a number of contributors. Initial screening indicated the need for a few additional samples. It is hoped that these will be available at the time of the Annual Meeting and that a final set of samples can be selected at that time. Plans are also under way to expand the initial set to include automatic welds and casting repair welds.

Subcommittee III on Magnetic Particle and Penetrant Testing (H. Migel, chairman) hopes to have its Procedure for Dry Powder Magnetic Particle Testing in final draft form by the time of the Annual Meeting, and has initiated work on a standard set of indications produced using this procedure.

Subcommittee IV on Technical, Economic, and Application Data (R. C. McMaster and S. A. Wenk, co-chairmen) has been responsible for preparation of the technical papers session on Non-Destructive Testing to be held Thursday, June 26. This session has a predominantly international flavor in keeping with the theme of the Annual Meeting and consists of seven papers from abroad and three from North America.[3]

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] 1949 Book of ASTM Standards, Part 1.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee V on Radiographic Procedure (C. H. Hastings, chairman) is attacking the problem of devising a specification suitable for assuring that radiographic inspection meets a prescribed quality standard. Although the project is still in a preliminary state, certain directions of attack seem to promise fruitful results and some progress is expected by the Annual Meeting.

Subcommittee VI on Ultrasonic Testing (J. C. Smack, chairman) is working on four projects: a glossary, a procedure for contact pulse testing using longitudinal waves, a procedure for resonance testing, and the development of suitable reference blocks. It is hoped that the last two projects will be sufficiently advanced by the time of the Annual Meeting so that results may be presented to the main committee for action.

This report has been submitted to letter ballot of the committee, which consists of 95 voting members; 62 members returned their ballots, of whom 56 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. BLY,
Chairman.

D. T. O'CONNOR,
Secretary.

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[3] Issued as separate publication *ASTM STP No. 145.*

REPORT OF COMMITTEE E-9

ON

FATIGUE*

Considerable interest in the statistical aspects of fatigue has been evidenced as a result of our Symposium at the 1951 Annual Meeting. This has resulted in publication of the papers in *Special Technical Publication No. 121* "Symposium on Statistical Aspects of Fatigue." As a follow-up of this interest, a session on Statistical Aspects of Fatigue was scheduled for the 1952 Annual Meeting with the following papers:[1]

"The Statistical Nature of the Fatigue Properties of SAE 4340 Steel Forgings," J. T. Ransom, E. I. du Pont de Nemours and Co., and R. F. Mehl, Carnegie Institute of Technology,

"The Statistical Behavior of Fatigue Properties and the Influence of Metallurgical Factors," E. Epremian and R. F. Mehl, Carnegie Institute of Technology,

"An Analysis of Scatter in Fatigue Testing," F. A. McClintock, Massachusetts Institute of Technology,

"A Statistical Interpretation of the Effect of Understressing on Fatigue Strength," E. Epremian and R. F. Mehl, Carnegie Institute of Technology, and

"Fatigue Properties of Large Specimens with Related Size and Statistical Effects," O. J. Horger and H. R. Neifert, Timken Roller Bearing Co.

A Task Group has been appointed to suggest testing procedures along statistical lines for guidance in formulating fatigue projects.

A sufficient number of papers have been accepted to make it possible to schedule two additional sessions on fatigue at the 1952 Annual Meeting. The papers that were presented follow:[2]

"Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum," T. J. Dolan and H. F. Brown, University of Illinois,

"An Investigation of the Coaxing Effect in Fatigue of Metals," G. M. Sinclair, University of Illinois,

"The Anisotropy of the Fatigue Properties of SAE 4340 Steel Forgings," J. T. Ransom, E. I. du Pont de Nemours and Co., and R. F. Mehl, Carnegie Institute of Technology,

"Fatigue Strength of 'Refractaloy-26' as Affected by Temperature, Hardness and Grain Size," F. C. Hull and P. R. Toolin, Westinghouse Electric Corp.,

"A Study of Fatigue of Steels Due to Repeated Applications of Mechanical Stresses in the Finite Region of the *S-N* Curves," W. G. Finch, The Johns Hopkins University,

"Plastic-Flow and Work-Hardening Phenomena in Fixed-Deflection Fatigue Tests of Magnesium Alloys," E. H. Schuette, The Dow Chemical Co.,

"Fatigue of 76S-T61 Aluminum Alloy Under Combined Bending and Torsion," W. N. Findley, University of Illinois,

"Fatigue Machines for Low Temperatures and for Miniature Specimens," W. N. Findley, University of Illinois, W. I. Mitchell, Iowa State College, and R. L. Sutherland, University of Iowa,

"Effect of Tensile and Compressive Fatigue Stress on Creep, Rupture, and Ductility Properties of Temperature Resistant Materials," B. J. Lazan, University of Minnesota, and E. Westberg, Syracuse University, and

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] These papers have been published as Symposium on Fatigue with Emphasis on Statistical Approach. II. (Issued as separate publication *ASTM STP No. 137*.)

[2] These papers appear in this volume of *Proceedings*.

"Dynamic Testing of Materials and Structures with a New Resonance Vibration Exciter and Controller," B. J. Lazan, A. Gannett, P. Kirmser, J. Klumpp, University of Minnesota, and J. Brown, Syracuse University.

The papers subcommittee is headed by W. T. Lankford.

An experiment was made during the year in providing a mimeographed list of references on fatigue for the preceding year (in this case, 1950). The lists were made available by Headquarters at a nominal price; the initial supply of 100 has been sold and a second group of 100 has now been made available. It is believed that this list has been useful, and it is proposed to continue a reference service of this general type.

Two years ago a survey of existing projects on fatigue was made and the results published as an Appendix to the Annual Report. This year a similar survey has been made and the results are given in the Appendix to this report. The subcommittee handling the above two projects is headed by T. J. Dolan.

Interest in tests of large members has continued. A subcommittee headed by J. M. Lessells has considered ways and means of sponsoring a program of bending and torsion fatigue tests of large members.

During the year the following members have been added to Committee E-9: A. B. Callender, Glenn L. Martin Co.; J. F. Millan, Caterpillar Tractor Co.; Arthur Schnitt, Bell Aircraft Co.

The election of officers for the ensuing term of two years has resulted in the selection of the following

Chairman, R. E. Peterson.

Secretary, O. J. Horger.

Advisory Committee, J. A. Bennett, T. J. Dolan, G. R. Gohn, L. R. Jackson, W. T. Lankford, J. M. Lessells, H. F. Moore, and R. L. Templin.

This report has been submitted to letter ballot of the committee, which consists of 42 members; 25 returned their ballots, of whom 24 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. E. PETERSON,
Chairman.

O. J. HORGER,
Secretary.

REPORT OF SURVEY OF FATIGUE PROJECTS

In accordance with the decision reached at the March meeting of Committee E-9, the Survey Subcommittee sent out a letter and questionnaire on April 1 to determine what new projects on fatigue properties of materials have been initiated since the previous survey conducted in 1950. The questionnaire was forwarded to a list of approximately 300 organizations compiled by the Subcommittee. Of the replies received, 49 organizations have reported 147 new projects currently being investigated. A list of these projects which supplements the information contained in the 1950 report of Committee E-9 is appended hereto.

Respectfully submitted on behalf of Subcommittee III,

T. J. Dolan,
Chairman.

APPENDIX

CURRENT PROJECTS ON FATIGUE PROPERTIES OF MATERIALS

1. *Aluminum Company of America:*

(*a*) Flexural fatigue strength of beams and beam splices.

(*b*) Effects of design details and variations in alloy on the fatigue strengths of structural and aircraft type connections.

(*c*) The effects of geometric stress raisers, including bosses (with and without holes) and ribs, on the fatigue strengths of castings.

(*d*) Fatigue strengths of commercial aluminum and magnesium alloys in presence of notches at elevated temperatures.

(*e*) Effects of cast notches and machined notches on fatigue strength of die-cast aluminum alloys.

2. *American Steel and Wire Division, U. S. Steel Co.:*

(*a*) Rotating beam fatigue tests on polished specimens of 40B37, 40C37, 80B37, 10B-38, A6037, and 40B37 low molybdenum steel.

(*b*) Torsion spring fatigue tests utilizing various *D*/*d* ratios, wire sizes, and treatments.

(*c*) Rotating strut fatigue limits on classes A, B, and C galvanized strand wire.

(*d*) Evaluation of property changes in drawn high carbon wire. Various steels will be used as well as the statistical approach to the evaluation of amounts and rates of wire drawing.

(*e*) Rotating strut fatigue limit on types 301, 302, 304, and 430 strand wire at room and subzero temperatures.

3. *Ampco Metal, Inc.:*

(*a*) Fatigue strength of sand cast, centrifugal cast, extruded, and rolled aluminum bronzes as a function of method of manufacture and alloy composition.

4. *American Brake Shoe Co.:*

(*a*) The relationship between chemical composition and fatigue limit of cast Hadfield's austenitic manganese steel.

5. *Armco Steel Corp.:*

(*a*) General study of the fatigue properties of stainless steel bars and wire.

(*b*) The effect of design, heat treatment, and surface on the fatigue properties of wrought steel railroad wheels.

(*c*) The fatigue properties of flat rolled Armco 17-7 PH in reversed bending.

(*d*) Types 430 and 430 Ti stainless—fatigue strength of welded joints in reversed bending.

6. *Bell Aircraft Corp.:*

(*a*) Low-cycle, high-stress, axial fatigue strength of plain and welded flat tension-specimens of 347, 410, and 403 stainless steels and 61S-T6 aluminum alloy.

(*b*) Room temperature and low temperature (−100 F) low-cycle, high-stress biaxial fatigue strength of 410 stainless steel tubes, notched and unnotched.

(*c*) The effect of cyanide cadmium plating and post-plating treatments on the fatigue strength of NE 8740 steel heat treated to 155,000 psi.

(*d*) The fatigue wear resistance of silicone rubber seats mounted on flapper valves.

(*e*) The effect of various materials and bonding materials on fatigue life of metal to metal bonds.

(*f*) The fatigue life of control bracket casting when loaded similarly to that experienced in flight.

(*g*) The fatigue strength of a main rotor mast assembly as a result of flight loads.

(*h*) Fatigue test of rotor hub: how shock loads affect fatigue life.

(*i*) Fatigue test of modified ventral fin.

(*j*) Fatigue test of steel main helicopter rotor hub.

(*k*) Flight fatigue loads of modified engine mounts to compare flight and fatigue test stresses.

(*l*) The optimum configuration of engine mount to produce a satisfactory fatigue life.

(*m*) Fatigue test of model 47 metal antitorque rotor blades (riveted).

(*n*) Fatigue tests of metal to metal bonds using a rotating beam testing machine.

(*o*) The flexural fatigue life of bonded blade specimens.

7. *Bell Telephone Laboratories, Inc.:*

(*a*) The influence of metallurgical variables on the flexural fatigue properties of copper-nickel-zinc alloys (nickel silver) sheet and strip.

8. *Bureau of Mines (Canada):*

(*a*) Effect of fretting corrosion on fatigue strength in presence of various inhibitors.

(*b*) Effect of shot peening and method of heat treatment on large suspension springs.

9. *Battelle Memorial Institute:*

(*a*) Factors involved in fatigue of a composite structure (such as a box-beam) in comparison with those in laboratory tests of simple specimens.

10. *Case Institute of Technology:*

(*a*) Low-cycle (high-strain) fatigue effects in metals.

11. *Columbia University, Department of Civil Engineering:*

(*a*) Statistical aspects of fatigue: character of distribution functions of N at constant stress..

12. *Consolidated Vultee Aircraft Corp.:*

(*a*) Torsional fatigue life of rudder spring tubes as used in an airplane.

13. *Cornell Aeronautical Laboratory, Inc.:*

(*a*) Effect of fatigue load on the bond between fiberglas material.

14. *Curtiss-Wright Corp., Propeller Division:*

(*a*) Comparison of longitudinal and transverse properties of extruded SAE 4330 at a hardness level of Rockwell C 30. Specimen types include uniform diameter, 0.002 in. radius, 60 deg notch and 0.010 in. radius, 60 deg notch.

(*b*) Same as Item (*a*) except at Rockwell C 40 hardness.

(*c*) Comparison of longitudinal specimens welded by atomic hydrogen and union melt methods using a modified SAE 6130 welding wire. Specimens of SAE 4330 uniform diameter and heat treated to Rockwell C 30.

(*d*) Comparison of longitudinal and transverse properties of Alcoa 76S-T61 using R. R. Moore type specimens.

(*e*) Comparison of the properties obtained on QQ-B-726, Grade C manganese bronze alloy by variations in casting practice and surface working.

15. *Department of the Army, Paint and Chemical Laboratory, Development and Proof Services, Aberdeen Proving Ground, Md.:*

(*a*) Hydrogen embrittlement inhibitors for SAE 1020 and 1095.

16. *Douglas Aircraft Co., Inc.:*

(*a*) Fatigue strength of hydraulic tubing as affected by wall thickness, manufacturing variables; comparison of aluminum alloy with stainless steel.

17. *E. I. du Pont de Nemours and Co., Inc.:*

(*a*) Fatigue of SAE 4340 under compressive stress—The Goodman Diagram for cases of compressive mean stress.

(*b*) Transverse fatigue strength of high purity SAE 4340 steel forgings.

(*c*) The effect of polishing stresses on fatigue strength of laboratory specimens of SAE 4340.

(*d*) The effect on the fatigue strength of thin temper films from stress relief heat treatment.

(*e*) The effect of additive-type lubricating oil on fatigue strength of SAE 4340 at 300 cycles per minute.

18. *Fatigue of Materials Laboratory (Princeton, N. J.):*

(*a*) The study of recrystallization phenomena in some non-ferrous metals under variable stress.

19. *École Polytechnique:*

(*a*) Fatigue tests on beams up to 12 in. in depth of killed, semi-killed, and rimmed steel at room and subzero temperature of −30 F; study of the brittle fracture in mild steel.

(*b*) Fatigue testing on triaxial specimens under tension-tension and compression-tension loading.

(*c*) Fatigue tests with model pressure vessels of mild steel and low-alloy, high-strength steel under repeated pressure up to 10,000 psi.

(*d*) Fatigue impact testing under tension-compression loading regarding the investigation of the Bauschinger effect under repeated loads in the neighborhood of the original elastic limit of the material.

20. *Goodyear Aircraft Corp.:*

(*a*) Fatigue strength aluminum honeycomb sandwich material.

21. *Gulf Research and Development Co.:*

(*a*) The effect of various strand and core lubricants on the fatigue properties of wire rope.

22. *International Harvester Co.:*

(*a*) The effect of decarburization and carbon restoration on the fatigue properties of SAE Grade 8 bolts.

(*b*) The fatigue strength of nodular iron in comparison with cast steel.

(*c*) Induction hardening of transmission gears; the comparative fatigue strength of 7-pitch transmission gears.

(*d*) The fatigue strength of 7-pitch carburized emergency alloy steel gears.

(*e*) Rotating beam fatigue strength of oil and air hardening tool steels, notched and unnotched.

(*f*) Comparative reverse bending fatigue strength of straight and cross-rolled C-1085 strip steel.

(*g*) Comparative bending fatigue properties of carbon *versus* alloy steel SAE Grade 8 bolts.

(*h*) Tensile fatigue properties of hexagon head 50B40 steel SAE Grade 8 bolts at various hardness levels.

(*i*) The effect of the number of threads exposed on the tensile fatigue properties of 50B40 steel SAE Grade 8 bolts.

23. *Joy Manufacturing Co.:*

(*a*) Effect of case hardening on the useful life of tungsten carbide tipped rock drill bits.

24. *Krouse Testing Machine Co.:*

(*a*) Endurance properties of structural parts when subjected to maximum service stresses:

(*1*) Service testing of propellers.

(*2*) Service testing of propeller hubs.

(*3*) Service testing of truck axles.

25. *Lebanon Steel Foundry:*

(*a*) Study of fatigue properties of cast carbon low-alloy and high-alloy steels.

26. *Link-Belt Co.:*

(*a*) Axial fatigue testing of sprocket chain.

(*b*) Simulated service testing of sprocket chains.

(*c*) Axial fatigue testing of sprocket chain fabricated with boron-treated pins.

27. *Menasco Manufacturing Co.:*

(*a*) Determination of endurance limit and notch sensitivity of high strength titanium alloy for use in aircraft landing gear.

28. *National Advisory Committee for Aeronautics:*

(*Lewis Laboratory*)

(*a*) Effects of cold work, heat treatment surface finish, and shape on the fatigue properties of the high-temperature alloy, N-155.

(*b*) Tensile fatigue tests of turbine blade materials at 1500 F with high mean stress superimposed.

(*c*) High-frequency fatigue properties of turbine blade materials at elevated temperatures.

(*University of California*)

(*a*) Survey of fatigue from fundamental viewpoint.

(*Langley Laboratory*)

(*a*) Axial load fatigue properties of 61S-T6 aluminum alloy and 347 and 403 stainless steel sheet materials.

(*b*) Electron microscope studies of crack initiation.

(*c*) A study of plastic stress concentration factors under completely reversed load.

29. *National Bureau of Standards, Metallurgy Division:*

(*a*) Effect of mechanical and thermal treatments on steel previously damaged by fatigue stressing.

(*b*) Study of metallurgical factors affecting notch sensitivity in fatigue.

(*c*) Fatigue properties of music wire and springs.

30. *Naval Air Material Center, Naval Air Experimental Station, Aero Materials Laboratory:*

(*a*) Comparison of fatigue characteristics of drilled specimens with those punched with different degrees of severity of cold work; each condition to be evaluated before and after exposure to corrosive medium.

(*b*) Evaluation of fatigue characteristics of boron-treated steels.

(*c*) Evaluation of fatigue characteristics of XA78S aluminum alloy.

(*d*) Fatigue tests of aluminum and magnesium casting alloys containing various degrees of dispersed discontinuities.

(*e*) Elevated temperature (1500 F) fatigue tests of vitallium, die-cast and precision-cast.

(*f*) Fatigue, creep, and impact tests of 3 per cent aluminum–5 per cent chromium titanium alloy at various temperatures.

(*g*) The effects on fatigue and notch-fatigue of steels when subjected to martempering, austempering, and conventional heat treatment.

(*h*) Application of ultrasonics to the spot welding of aluminum alloys, fatigue strength of spot welds.

(*i*) Investigation of spot and seam weld characteristics of titanium and titanium base alloys.

31. *Naval Research Laboratory:*

(*a*) Electrical resistance changes in metals as a function of fatigue.

(*b*) Influence of grain size on high temperature fatigue.

32. *Ohio State University, Department of Mechanical Engineering:*

(*a*) An investigation of the effects of double harmonic uniaxial cyclic stresses on the fatigue endurance limits of metals.

(*b*) An investigation of the effects of stepwise varying magnitudes of uniaxial cyclic stresses on the fatigue endurance limits of metals.

33. *Oregon State College, Department of Mechanical Engineering:*

(*a*) Fatigue properties of zirconium.

34. *The Pennsylvania Railroad Co.:*

(*a*) Fatigue of nut locks for track bolts in repeated compression of the coil of the nut-lock or spiral lock washer (stresses in the washer are bending and torsion).

35. *The Pennsylvania State College, Department of Engineering Mechanics:*

(*a*) A study of cumulative fatigue damage in SAE 4320 steel.

36. *Revere Copper and Brass, Inc.:*

(*a*) Fatigue strength of 90:10 cupronickel.

(*b*) Fatigue strength of tin-bearing brasses in strip form.

37. *Rohm and Haas:*

(*a*) The fatigue strength of methyl methacrylate base organic, transparent plastics.

38. *Signal Corps Engineering Laboratories, Materials Section:*

(*a*) Low temperature fatigue properties of metals down to −100 F.

39. *Sonntag Scientific Corp.:*

(*a*) Fatigue strength of thin plates.

40. *Steel Founders' Society of America:*

(*a*) An investigation of the endurance properties of various cast steels.

41. *University of Illinois, Department of Civil Engineering:*

(*a*) A study of the effect of hydrogen and residual stress on the fatigue strength of welded connections.

(*b*) Fatigue tests on cumulative damage in structural joints.

42. *University of Illinois, Department of Theoretical and Applied Mechanics:*

(*a*) The influence of grain size on the notch sensitivity of 70-30 brass subjected to repeated loads.

(*b*) Fatigue tests of railroad joint bars.

(*c*) Determination of residual stresses in beams following repeated loading.

(*d*) Fatigue tests of hardened steel rollers.

(*e*) Behavior of $\frac{3}{4}$-in. steel plate subjected to repeated loads causing biaxial stress.

(*f*) An appraisal of the Prot method of fatigue testing.

(*g*) Statistical aspects of the effect of fluctuating stress amplitude on fatigue life of 75S-T6 aluminum alloy.

(*h*) Repeated load tests of cast steel.

(*i*) An X-ray and electron micrographic examination of the effects of tensile and compressive cold work on the fatigue life of Armco iron.

(*j*) Theory of fatigue based on a statistical distribution of grain size.

43. *University of Illinois, Department of Ceramic Engineering:*

(*a*) The effect of ceramic coatings on the fatigue strength and fatigue life of selected metals.

44. *University of Michigan, Engineering Research Institute:*

(*a*) Effect of chromium plating on fatigue strength.

45. *University of Minnesota, Engineering Experiment Station:*

(*a*) Damping, elasticity, and fatigue properties of materials at room and elevated temperatures.

(*b*) Resonance damping, elasticity, and fatigue properties of materials and structural units.

(*c*) Axial stress, fatigue properties of unnotched and notched materials at various stress ratios and at elevated temperatures.

(*d*) Investigation of accelerated methods for determining fatigue strength.

46. *U. S. Naval Engineering Experiment Station, Navy Department:*

(*a*) Effects of various keyway designs on the flexural fatigue properties of propulsion shafting.

(*b*) Effects of peening and root fillet design on flexural fatigue of a steam turbine blade.

(*c*) Surface fatigue (rolling contact) of ball bearing materials.

(*d*) Mechanical and physical properties of 70:30 and 90:10 copper-nickel alloys.

(*e*) General properties, including fatigue, of representative nodular irons.

(*f*) Sea water corrosion-fatigue of nonferrous metals.

47. *Wayne University, College of Engineering:*

(*a*) Endurance limit and effect of various surface treatments on Discalloy.

48. *Westinghouse Research Laboratories:*

(*a*) Investigation of the effect of notches upon the fatigue strength of high temperature alloys.

(*b*) A statistical study of the fatigue strength of medium carbon steel.

(*c*) Investigation of the fatigue properties of titanium alloys.

(*d*) Determination of the effect of variations in casting technique on the fatigue properties of "precision-cast" high-temperature alloys.

49. *Wright Air Development Center, Aeronautics Division:*

(*Propeller Laboratory*)

(*a*) To determine the distribution of endurance limits for flash welds used in propeller blade fabrication by means of statistical type fatigue tests.

(*b*) To establish better quality control of silver brazed joints by means of statistical type fatigue testing.

(*c*) To determine the effect of galling on the fatigue properties of titanium alloys.

(*d*) To develop a fatigue testing machine for testing structural samples from propeller blades at 1100 cps in bending.

(*e*) To determine the fatigue strength of steel spars for helicopters.

(*f*) To determine the fatigue properties of bolted joints used on electric propeller and rotor test rigs.

(*g*) To investigate the fatigue properties of full scale flash-welded steel propeller blades.

(*Materials Laboratory*)

(*a*) Investigate means of detecting fatigue damage prior to the initiation of a crack.

(*b*) Investigate the effects of varying the speed of the cyclic load over a wide range on the fatigue and dynamic creep properties of heat-resistant alloys.

(*c*) Investigate the damaging effect of prior creep on the fatigue properties at elevated temperature of heat-resistant materials.

(*d*) Axial loading and bending fatigue properties of magnesium alloy forgings, comparison of constant deflection and constant load fatigue.

(*e*) To obtain the elevated temperature axial loading fatigue and dynamic creep properties, as a function of mean stress and temperature, for alloy steel and titanium alloy.

(*f*) To investigate the accuracy and feasibility of the Prot method for accelerated fatigue testing.

(*c*) Fatigue properties of music wire and springs.

30. *Naval Air Material Center, Naval Air Experimental Station, Aero Materials Laboratory:*

(*a*) Comparison of fatigue characteristics of drilled specimens with those punched with different degrees of severity of cold work; each condition to be evaluated before and after exposure to corrosive medium.

(*b*) Evaluation of fatigue characteristics of boron-treated steels.

(*c*) Evaluation of fatigue characteristics of XA78S aluminum alloy.

(*d*) Fatigue tests of aluminum and magnesium casting alloys containing various degrees of dispersed discontinuities.

(*e*) Elevated temperature (1500 F) fatigue tests of vitallium, die-cast and precision-cast.

(*f*) Fatigue, creep, and impact tests of 3 per cent aluminum–5 per cent chromium titanium alloy at various temperatures.

(*g*) The effects on fatigue and notch-fatigue of steels when subjected to martempering, austempering, and conventional heat treatment.

(*h*) Application of ultrasonics to the spot welding of aluminum alloys, fatigue strength of spot welds.

(*i*) Investigation of spot and seam weld characteristics of titanium and titanium base alloys.

31. *Naval Research Laboratory:*

(*a*) Electrical resistance changes in metals as a function of fatigue.

(*b*) Influence of grain size on high temperature fatigue.

32. *Ohio State University, Department of Mechanical Engineering:*

(*a*) An investigation of the effects of double harmonic uniaxial cyclic stresses on the fatigue endurance limits of metals.

(*b*) An investigation of the effects of stepwise varying magnitudes of uniaxial cyclic stresses on the fatigue endurance limits of metals.

33. *Oregon State College, Department of Mechanical Engineering:*

(*a*) Fatigue properties of zirconium.

34. *The Pennsylvania Railroad Co.:*

(*a*) Fatigue of nut locks for track bolts in repeated compression of the coil of the nut-lock or spiral lock washer (stresses in the washer are bending and torsion).

35. *The Pennsylvania State College, Department of Engineering Mechanics:*

(*a*) A study of cumulative fatigue damage in SAE 4320 steel.

36. *Revere Copper and Brass, Inc.:*

(*a*) Fatigue strength of 90:10 cupro-nickel.

(*b*) Fatigue strength of tin-bearing brasses in strip form.

37. *Rohm and Haas:*

(*a*) The fatigue strength of methyl methacrylate base organic, transparent plastics.

38. *Signal Corps Engineering Laboratories, Materials Section:*

(*a*) Low temperature fatigue properties of metals down to −100 F.

39. *Sonntag Scientific Corp.:*

(*a*) Fatigue strength of thin plates.

40. *Steel Founders' Society of America:*

(*a*) An investigation of the endurance properties of various cast steels.

41. *University of Illinois, Department of Civil Engineering:*

(*a*) A study of the effect of hydrogen and residual stress on the fatigue strength of welded connections.

(*b*) Fatigue tests on cumulative damage in structural joints.

42. *University of Illinois, Department of Theoretical and Applied Mechanics:*

(*a*) The influence of grain size on the notch sensitivity of 70-30 brass subjected to repeated loads.

(*b*) Fatigue tests of railroad joint bars.

(*c*) Determination of residual stresses in beams following repeated loading.

(*d*) Fatigue tests of hardened steel rollers.

(*e*) Behavior of $\frac{3}{4}$-in. steel plate subjected to repeated loads causing biaxial stress.

(*f*) An appraisal of the Prot method of fatigue testing.

(*g*) Statistical aspects of the effect of fluctuating stress amplitude on fatigue life of 75S-T6 aluminum alloy.

(*h*) Repeated load tests of cast steel.

(*i*) An X-ray and electron micrographic examination of the effects of tensile and compressive cold work on the fatigue life of Armco iron.

(*j*) Theory of fatigue based on a statistical distribution of grain size.

43. *University of Illinois, Department of Ceramic Engineering:*

(*a*) The effect of ceramic coatings on the fatigue strength and fatigue life of selected metals.

44. *University of Michigan, Engineering Research Institute:*

(*a*) Effect of chromium plating on fatigue strength.

45. *University of Minnesota, Engineering Experiment Station:*

(*a*) Damping, elasticity, and fatigue properties of materials at room and elevated temperatures.

(*b*) Resonance damping, elasticity, and fatigue properties of materials and structural units.

(*c*) Axial stress, fatigue properties of unnotched and notched materials at various stress ratios and at elevated temperatures.

(*d*) Investigation of accelerated methods for determining fatigue strength.

46. *U. S. Naval Engineering Experiment Station, Navy Department:*

(*a*) Effects of various keyway designs on the flexural fatigue properties of propulsion shafting.

(*b*) Effects of peening and root fillet design on flexural fatigue of a steam turbine blade.

(*c*) Surface fatigue (rolling contact) of ball bearing materials.

(*d*) Mechanical and physical properties of 70:30 and 90:10 copper-nickel alloys.

(*e*) General properties, including fatigue, of representative nodular irons.

(*f*) Sea water corrosion-fatigue of nonferrous metals.

47. *Wayne University, College of Engineering:*

(*a*) Endurance limit and effect of various surface treatments on Discalloy.

48. *Westinghouse Research Laboratories:*

(*a*) Investigation of the effect of notches upon the fatigue strength of high temperature alloys.

(*b*) A statistical study of the fatigue strength of medium carbon steel.

(*c*) Investigation of the fatigue properties of titanium alloys.

(*d*) Determination of the effect of variations in casting technique on the fatigue properties of "precision-cast" high-temperature alloys.

49. *Wright Air Development Center, Aeronautics Division:*

(*Propeller Laboratory*)

(*a*) To determine the distribution of endurance limits for flash welds used in propeller blade fabrication by means of statistical type fatigue tests.

(*b*) To establish better quality control of silver brazed joints by means of statistical type fatigue testing.

(*c*) To determine the effect of galling on the fatigue properties of titanium alloys.

(*d*) To develop a fatigue testing machine for testing structural samples from propeller blades at 1100 cps in bending.

(*e*) To determine the fatigue strength of steel spars for helicopters.

(*f*) To determine the fatigue properties of bolted joints used on electric propeller and rotor test rigs.

(*g*) To investigate the fatigue properties of full scale flash-welded steel propeller blades.

(*Materials Laboratory*)

(*a*) Investigate means of detecting fatigue damage prior to the initiation of a crack.

(*b*) Investigate the effects of varying the speed of the cyclic load over a wide range on the fatigue and dynamic creep properties of heat-resistant alloys.

(*c*) Investigate the damaging effect of prior creep on the fatigue properties at elevated temperature of heat-resistant materials.

(*d*) Axial loading and bending fatigue properties of magnesium alloy forgings, comparison of constant deflection and constant load fatigue.

(*e*) To obtain the elevated temperature axial loading fatigue and dynamic creep properties, as a function of mean stress and temperature, for alloy steel and titanium alloy.

(*f*) To investigate the accuracy and feasibility of the Prot method for accelerated fatigue testing.

REPORT OF COMMITTEE E-11
ON
QUALITY CONTROL OF MATERIALS*

Since the publication in 1951 of the ASTM Manual on Quality Control of Materials prepared by Committee E-11, the committee has been carrying forward a number of projects aimed at promoting the use of statistical methods in the standardization work of the Society.

Task groups have been working on recommended practices and procedures in the planning of interlaboratory test programs, in the determination of the number of tests for a desired precision of an average, in the sampling of bulk materials, and the fitting of curves for linear relationships. The study of problems concerned with the use of the terms "Precision and Accuracy" is being carried on. The results of this work will materialize in the form of additions to the ASTM Manual on Quality Control of Materials.

A symposium on Bulk Sampling sponsored by Committee E-11 was held June 18, 1951, at the Annual Meeting of the Society. The proceedings were presented in *Special Technical Publication No. 114.*

Committee E-11 has given assistance to other ASTM Committees and members on problems covering special phases of application of statistical methods to ASTM problems.

The election of officers to serve for the ensuing term of two years has resulted in the selection of the following:

Chairman, H. F. Dodge.
Vice-Chairman, A. E. R. Westman.
Secretary, O. P. Beckwith.
Advisory Committee, W. J. Youden and W. E. Deming.

This report has been submitted to letter ballot of the committee, which consists of 19 members; 16 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. F. Dodge,
Chairman.

O. P. Beckwith,
Secretary.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

REPORT OF COMMITTEE E-12
ON
APPEARANCE*

Committee E-12 on Appearance held two meetings during the year: the first at Atlantic City, N. J., on June 20, 1951, and the second at Cleveland, Ohio, on March 6, 1952. Meetings of the Advisory Committee were held in Atlantic City on June 19, 1951, in New York, N. Y., on February 8, 1952, and in Cleveland, Ohio, on March 5, 1952.

The committee records with regret the death of one of its active members, Alvin Goetz.

On February 9, 1952, M. Rea Paul, as chairman of the ASTM delegation to the Inter-Society Color Council, presented a report of progress on Appearance Specification. E. A. Zahn of this committee was appointed a delegate to the ISCC. W. J. Kiernan was appointed to represent the Society on the ASA Sectional Committee on Optics (Z58).

The election of officers resulted in the reelection of the present incumbents for the ensuing term of two years.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Definitions (R. S. Hunter, chairman) has given serious attention to definitions relating to gloss but is not yet prepared to recommend them for publication.

Subcommittee II on Color and Spectral Characteristics (Dorothy Nickerson, chairman).—The chairman of this subcommittee with the assistance of Francis Scofield and Richard Hunter made arrangements for the Symposium on Color Difference Specification[1] sponsored by Committee E-12 and held in Cleveland, Ohio, on March 6, 1952. The program was developed with the specific intention of familiarizing the membership with methods being employed for color control, and for the presentation of data to serve as specifications and tolerances. The Symposium comprised the following:

Introduction and Bibliography—Dorothy Nickerson
Specification of Color Tolerance for Carpet Wools—H. R. Davidson and Elaine Friede
Control of Small Color Differences in Plastics Manufacture—Lawrence Rudnick and George W. Ingle
Colored Glass Specifications with Single Number Tolerances—Norbert J. Kreidl and Tyler G. Pett
Industrial Color Tolerance Specifications—G. L. Buc
Report of Group 4, Subcommittee 10 of D-1 on Industrial Reproducibility—Francis Scofield
On the Specification of Color Differences in C.I.E. Coordinates—Daniel Smith
First Principles in the Expression of Color Differences—Sidney M. Newhall
Summary of Information and Points of View Developed During the Symposium—Deane B. Judd

As a result of this symposium a definite pattern is being established for detailed consideration of appearance problems at the 1953 Spring Meeting of this committee. This will be undertaken by Task

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Symposium on Color Difference Specification, Am. Soc. Testing Mats. (1952). (Issued as a separate publication.)

Group 2, under the chairmanship of Hugh S. Davidson. This task group will organize a study of the instrumentation available for color difference measurement, methods for their most effective use, and an evaluation of reproducibility.

In addition to this development along the lines of the symposium, several other color problems came up for consideration. Notably, the committee decided to undertake an investigation of the specification of the color of transparent liquids. This problem was introduced by Francis Scofield, with particular interest indicated in the amber range typical of natural oil products. Dean Farnsworth will serve as chairman of Task Group 3 to organize and carry on a study of this problem.

Task Group 4 under the chairmanship of Deane B. Judd has been organized to study colorimetric specification from spectrophotometric measurements.

Task Group 1 has already achieved much under the chairmanship of Harry K. Hammond, III. This group has drawn up a Proposed Method of Test for Reflectance of Opaque Specimens for further consideration by this committee and Committees C-22 on Porcelain Enamel and D-1 on Paint, Varnish, Lacquer, and Related Products.

Under the jurisdiction of this subcommittee, the committee as a whole voted to review ASA Standards on Spectrophotometry, Color, and Color Specifications (ASA Nos.: Z58.7.1, Z58.7.2, and Z58.7.3), for possible adoption by ASTM.

Subcommittee III on Gloss and Geometric Characteristics (H. K. Hammond, III, chairman) has considered many fundamental problems related to the application of goniophotometric methods for the specification of gloss. Because of the limited number of laboratories having goniophotometers and the impossibility of undertaking cooperative studies at this time, the committee as a whole has gone on record as having interest in the work being done by I. Nimeroff at the National Bureau of Standards and by Daniel Smith. Reports of progress will be made to this committee.

This report has been submitted to letter ballot of the committee, which consists of 62 members; 46 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

M. REA PAUL,
Chairman.

DANIEL SMITH,
Secretary.

TECHNICAL PAPERS

With Discussions

EDGAR MARBURG LECTURE

THE PURPOSE of the Edgar Marburg Lecture is to have described at the Annual Meetings of the American Society for Testing Materials, by leaders in their respective fields, outstanding developments in the promotion of knowledge of engineering materials. Established as a means of emphasizing the importance of promoting knowledge of materials, the Lecture honors and perpetuates the memory of Edgar Marburg, first Secretary of the Society.

NONDESTRUCTIVE TESTING[1]

TWENTY-SIXTH EDGAR MARBURG LECTURE

BY ROBERT C. MCMASTER[2]

Nondestructive testing is a normal human sensory technique. Its extension through scientific methods has increased its scope, sensitivity, and reliability until it has become a vital operation in modern industrial production and quality control. Misuse or omission of appropriate nondestructive tests on critical structures or equipment is sometimes disastrous. Proper application of nondestructive tests lowers production costs, increases industrial productivity, and insures reliability and safety in service.

Basically, the art of nondestructive testing includes *all possible methods* of detection or measurement of the properties or performance capabilities of materials, parts, assemblies, structures, and machines, *which do not damage or destroy their serviceability*. By definition, nondestructive tests differ from all tests and measurements which can be achieved only through damage to, or destruction of, the serviceability of the test objects. The latter are known as *destructive* tests.

Any valid law of nature may serve as a basis for a useful nondestructive test—if it provides reliable measurements that can be correlated with material properties or discontinuities and with serviceability. Modern nondestructive tests are of three general types:

1. Those involving transmission of energy,
2. Those involving transport of matter, and
3. Those involving combinations of matter transport and energy transfer,

in their probing media. *Transport of matter*, as used in mechanical gaging, fluid penetrant and leak tests; filtered particle tests, and others, is generally useful only for nondestructive testing of *exposed surfaces*, or of surfaces connected to exposed surfaces by open channels, of test objects. *Transmission of energy*, as used in X-ray, magnetic and electric field tests, and others, may reveal structure and discontinuities *within materials*, or on surfaces of *enclosed cavities*. *Combined transfer of energy and matter* provides powerful additional nondestructive test methods, such as the ultrasonic, electromagnetic induction, and nucleonic types, capable of probing very thick or very thin layers of materials, or of producing informative secondary reactions which reveal material properties. Usually more than one of these types of nondestructive tests must be employed for complete inspection of test objects in industry.

Nondestructive testing is fact finding, even when the facts are hidden from ordinary observations. It is an extension of human observations. It may or may not require a human operator to evaluate the observations. In most cases it is possible, by means of adequate research and development, to develop machines which replace some or all of the functions of a human inspector. Where standards of serviceability are well established and where extensive past experience exists, it sometimes becomes feasible to develop fully automatic nondestructive-testing devices. These may not only measure the significant properties of the test object but also judge and decide upon its acceptability or rejection. Such developments of automatic machines are usually justified only when:

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[1] Presented at the Fifty-fifth Annual Meeting of the Society, June 25, 1952, New York, N. Y.

[2] Supervisor, Electrical Engineering Division, Battelle Memorial Inst., Columbus, Ohio.

1. A large number of inspections must be made;
2. The value of each test object is great;
3. The test object itself is cheap but is critical to human life or safety or to the performance and serviceability of a costly assembly, such as a large airplane; or
4. The object when tested is cheap, but if accepted, will be given costly further fabrication or treatments so that it is ultimately very costly. In this case, the prior nondestructive test saves the costs which would otherwise be wasted in the expensive finishing of the piece.

All too often, those who are unfamiliar with the basic nature of nondestructive tests expect them to work miracles. If X-rays or ultrasonic waves permit one to "see" through opaque solid objects, can they not be expected to provide other magic solutions to our production problems? Not at all! Nondestructive tests usually reveal only the specific kinds of defects and conditions they were designed to reveal. What to do about the situations so revealed is a problem for production and engineering management to solve. The nondestructive test can never be expected to make up for the lack of specific knowledge of the nature of materials, of the causes of service failures, or of the sources of production difficulties. However, nondestructive tests can provide additional factual data concerning such defects and conditions, on the basis of which engineering management can make a more intelligent analysis. And nondestructive tests can monitor the effects of corrective changes in production conditions or operations, to show whether or not the difficulties are being eliminated.

Misconceptions usually lead to misapplications of nondestructive tests and to failures which are not rightly the fault of the test method. A typical misconception is the assumption that if a part has been given a specific nondestructive test—let us say, by X-rays—and been passed, then the part, and the method by which it was produced, are acceptable, possibly even perfect. This is usually untrue. Nondestructive tests are *specific* to certain types of materials, conditions, and defects.

X-rays are capable of revealing a multitude of different material conditions, but there are other common undesirable conditions they frequently do not reveal. Typical of these might be laminations perpendicular to the direction of the X-ray beam, or fine, tightly closed cracks near the surface. The laminations might be clearly revealed by an ultrasonic test. The tight cracks might best be detected by magnetic-particle or penetrant inspection, as appropriate to the material in question. What a nondestructive test is capable of revealing, it usually does show reliably. But it says nothing about other possible conditions, outside the scope of its detection.

THE USES OF NONDESTRUCTIVE TESTS

There are many specific jobs which nondestructive tests can do well. However, no single nondestructive test can necessarily do them all, even for a single material. And a single job may need different nondestructive tests when the material is changed. The nondestructive tests are, in general, specific. The test must be selected in accordance with the material, the conditions to be detected, and the job to be done. Furthermore, the purpose of the nondestructive test may change in accordance with the step in the production process at which it is applied.

The ultimate purpose of all nondestructive tests is to evaluate the quality, strength, discontinuities, or serviceability properties of materials, parts, structures, and assemblies, without damage to the test objects. The specific purpose may vary greatly, within this over-all objective. Typical uses made of nondestructive tests in industry include:

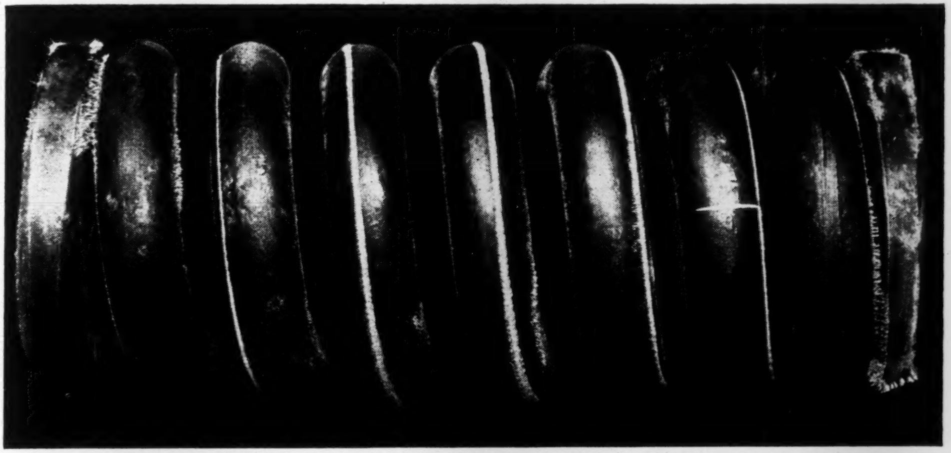


FIG. 1.—Magnaflux (Dry Grey Powder) Magnetic-Particle Indication of a Seam in a Locomotive Spring. This defect was present in the bar stock prior to its fabrication into the spring. (Courtesy Magnaflux Corp., Chicago, Ill.)

FIG. 2.—Fisher Steelsorter Used in Stock Room to Sort and Classify Mixed Steel Bars by Electromagnetic Induction Testing. (Courtesy Fisher Scientific Co., Pittsburgh, Pa.)

1. *Identification, sorting, and selection of raw materials* to determine:

(*a*) That the material meets specifications, and is actually the material it is supposed to be.

(*b*) That it is free from undesirable inhomogeneities or defects (Fig. 1).

(*c*) That it does not consist of accidentally mixed lots (Fig. 2).

(*d*) That (in case the material has previously been subject only to percentage quality control methods) every unit in the lot meets the specifications established for the lot.

2. *Checking the chemical composition*, to establish:

(*a*) That chemical composition variations within the lot are within acceptable limits.

(*b*) That processing steps have not produced damaging local variations in composition in single units (such as decarburization, "burnt steel," segregation of eutectic in alloys, excessive carbon content, etc.). Such checking is often particularly critical in the case of exposed surface layers, which may later be subjected to case-hardening or shot peening, or to corrosion or fatigue loading in service. On the other hand, damage to such surface layers may be inconsequential if they are to be removed in later processing steps. In this case, nondestructive tests sensitive only to the surface layers would be quite useless at this stage in processing.

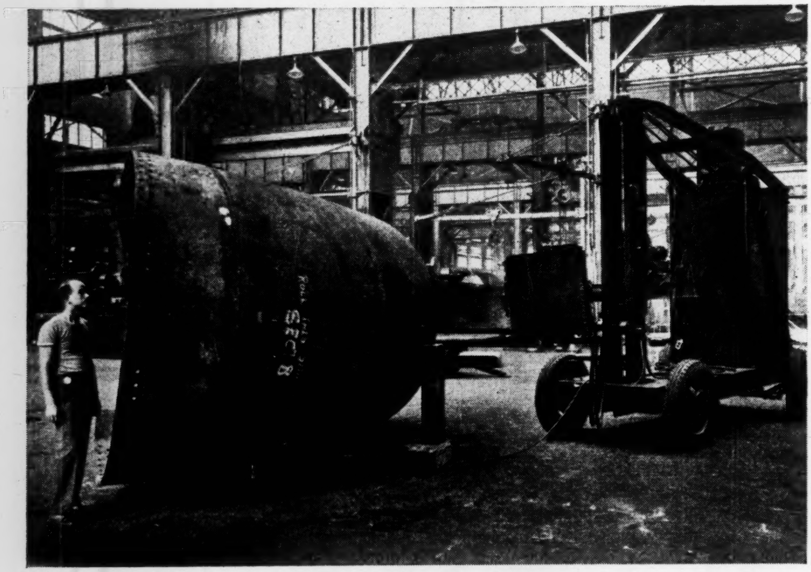


FIG. 3.—Radiography of Heavy Welded Structure with General Electric Portable 250-kvp X-ray. (Courtesy General Electric X-ray Div., Milwaukee, Wis.)

(*c*) That all essential processing steps which influence composition have been included for all units.

(*d*) That plating, cladding, and other dissimilar surface layers are of the proper composition, thickness, and adherence.

3. *Detecting variations in metallurgical structure*, such as might accompany:

(*a*) Heat treating or annealing in oxidizing, reducing, carburizing, or nitriding atmospheres.

(*b*) Heating, cooling, and aging so as to cause transitions in structure.

(*c*) Differences between cast and wrought structures (as might be present after fusion welding of wrought products).

(*d*) Treatments (including cooling) which influence grain size or grain-boundary conditions.

4. *Detecting conditions of mechanical stress*, particularly residual stresses following:

(*a*) Heat treating or processing.

(*b*) Shot peening or mechanical surface rolling.

(*c*) Welding or joining.

(*d*) Surface finishing (including grinding, polishing, or chemical treatments).

(*e*) Case hardening by gas or induction heating, nitriding, or carburizing, etc.

(*f*) Bending, forming, or other fabrication operations.

(*g*) Repeated service stressing.

(*h*) Loading beyond the elastic limit.

5. *Detecting internal voids and fissures:* such as,

(*a*) Pipe or gas porosity in castings.

(*b*) Shrinkage and microshrinkage.

(*c*) Flakes or transverse fissures in railroad rails.

(*d*) Incomplete penetration or porosity in welds (Figs. 3 and 4).

(*e*) Nugget cracking and porosity in spot welds.

(*f*) Laminations in rolled plate and sheet materials.

6. *Detecting internal inclusions and forgien materials:* such as,

(*a*) Dross in cast metals and alloys.

(*b*) Slag inclusions in fusion weld metal.

(*c*) Electrode pickup in spot welding.

(*d*) Internal parts misplaced or loosened during assembly.

(*e*) Foreign bodies rolled or forged into materials.

7. *Detecting surface cracks and other defects connected with exposed external surfaces:* such as,

(*a*) Fatigue cracks developed under repeated loading (Fig. 5).

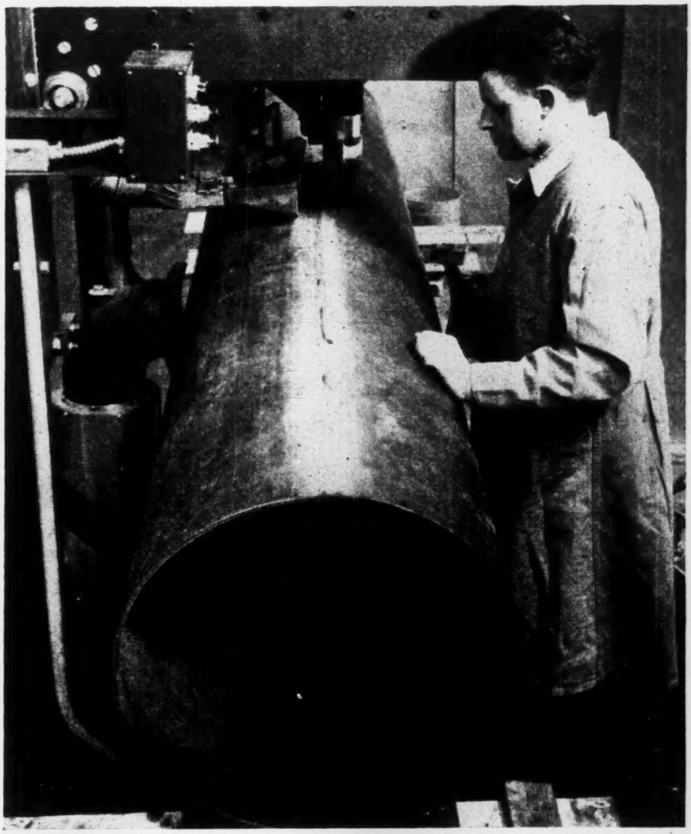


Fig. 4.—Magnaflux Automatic Dry Magnetic-Particle Inspection Unit for Resistance-Welded Line Pipe, Installed on Pipe Mill. Prompt detection of weld defects permits immediate correction of welding operation and repair of defects prior to hydrostatic proof test. (Courtesy Magnaflux Corp., Chicago, Ill.)

(*b*) Cracks resulting from surface grinding.

(*c*) Heat treating and thermal cracks.

(*d*) Seams and laps resulting from rolling and piercing or other hot forging operations.

(*e*) Cracks resulting from surface heat treatment, case hardening, nitriding, hydrogen embrittlements, etc.

(*f*) Corrosion pitting.

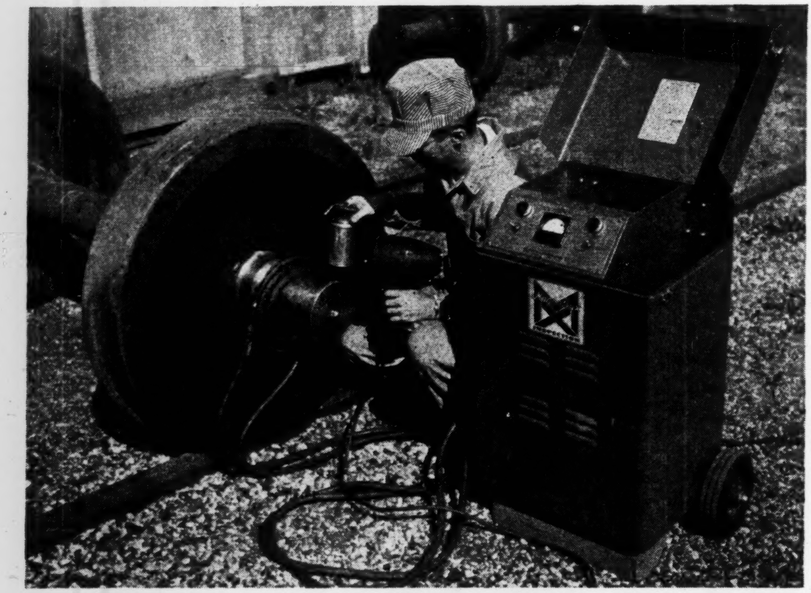


FIG. 5.—Detection of Service Fatigue Cracks in Railway Car Axle with Magnaflux Portable Wet-Method Magnetic-Particle Equipment. (Courtesy Magnaflux Corp., Chicago, Ill.)

8. *Gaging dimensions,* usually of finished parts, under conditions in which mechanical calipering by manual methods may not be feasible. Measurements which fall in this class include:

(*a*) Wall thickness of closed vessels, tubes, and pipes whose internal surfaces are not accessible (Fig. 6).

(*b*) Thickness of hot strip or other sheet materials moving at high velocities.

(*c*) Fluid levels in closed containers, such as molten metal level in furnaces and cupolas, radioactive materials in pipes and tanks, etc.

(*d*) Displacements of hidden parts of structures under high velocity or vibratory loads.

(*e*) Clearances between electrodes in sealed vacuum tubes.

(*f*) Location of internal insulation and bushings in electrical apparatus.

(*g*) Measurements of plating or cladding thicknesses.

The useful performance properties of materials or parts may be established or damaged at many different points in their production or fabrication processes. Consequently, nondestructive tests designed to detect such properties or damage may be needed at many different points in these production processes. Further damage might occur during transit, installation, calibration, or maintenance of finished products. Therefore, additional nondestructive tests may be required to detect this damage. Finally, service conditions, such as repeated loading, wear, corrosion, surface blows, and high temperatures, may also damage or destroy the serviceability of the material or part.

Thus, further nondestructive tests may be required periodically during service life.

Since the inherent useful properties of the material or part may be changed considerably during production, fabrication, or service (as, for example, during heat treating or welding or under dynamic loads), the nondestructive tests appropriate for evaluating these changing properties may vary accordingly.

For reasonable economy and efficiency in production and application, the appropriate nondestructive test should usually be applied *as early in the production or application process as the material properties permit.* For example, nondestructive tests which reveal rejectable defects in the *raw materials* may often be applied before any fabrication costs have been incurred. This saves the wasted costs of further fabricating of materials containing defects. Nondestructive tests designed to reveal damage from *fabricating processes* often may be applied *directly subsequent to the process* which may have produced the damage. This prevents the possibility of incurring further handling or fabrication costs on the worthless units. It permits immediate correction

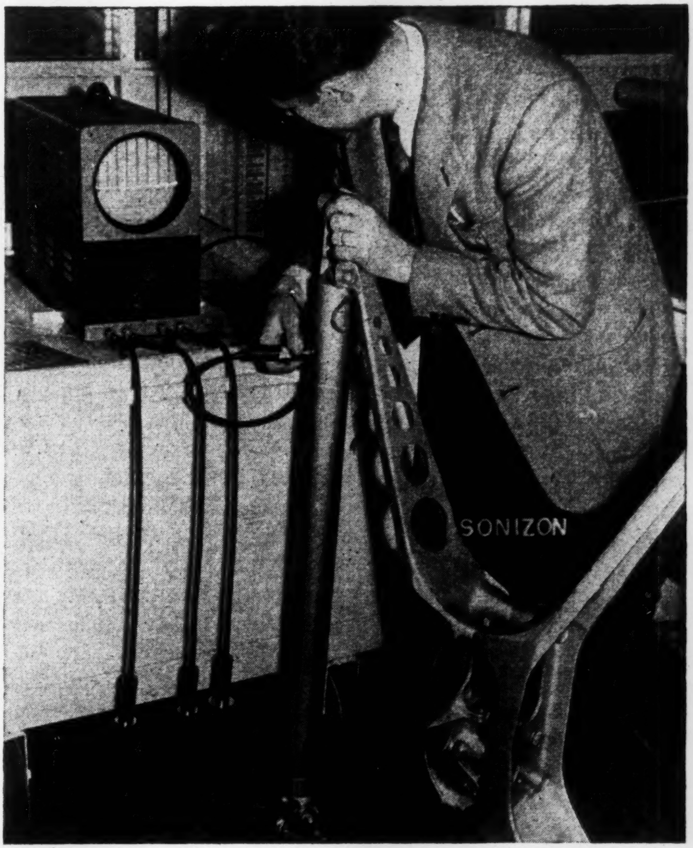


Fig. 6.—Magnaflux Sonizon Ultrasonic Resonance Equipment Used to Measure Wall Thickness of Tubular Aircraft Component. (Courtesy Douglas Aircraft Corp., Santa Monica, Calif., and Magnaflux Corp., Chicago, Ill.)

of the process. Even more important, prompt nondestructive testing often permits more sensitive and lower cost nondestructive testing. The specific damage may often be more easily and sensitively detected before it is hidden by the effects of further processing or fabrication.

DISTINGUISHING CHARACTERISTICS OF NONDESTRUCTIVE TESTS

Most nondestructive test methods evaluate the quality, strength, or serviceability characteristics of the test objects *indirectly*. Usually, they involve the measurement of a critical or useful property (such as strength or the presence of flaws) in terms of other related, but noncritical, properties. The latter often have little or no direct significance in the application. For example, the fatigue performance of a casting may be evaluated by tests of its magnetic discontinuities or X-ray absorption. Neither of these latter two properties has any ultimate usefulness or direct bearing on the fatigue life of the casting in service.

Most nondestructive test methods involve far more than simple visual inspection of the exposed surfaces of test objects. In many cases, the nondestructive tests are designed to reveal the properties, dimensions, and discontinuities of the interior of the specimens. Nearly every basic principle of physics has been used to obtain, nondestructively, this basic information concerning the internal condition of test objects.

Nondestructive tests differ from *percentage destructive tests*, or "*coupon tests*." In coupon tests, a selected fraction of all the units in a lot are mechanically loaded to failure or are cut apart for examination. The strength or condition of the few samples is determined destructively, after which the units tested are unfit for service. Often, only a portion of the selected object is tested. This may be done by cutting a tension test specimen from one portion of it, or by sectioning it and making a metallographic examination after polishing and chemically etching the sectioned surface. Tests of this type destroy the test samples.

The corresponding advantages and limitations of destructive and nondestructive test methods are listed side by side for easy comparison in Table I. From these comparisons, one may conclude that:

1. Destructive tests are often quantitative; nondestructive tests are most frequently qualitative only.

2. Nondestructive tests usually require considerable skill, experience, and judgment on the part of the inspector.

3. Nondestructive tests are to be preferred if there is large random variability within production lots, if the product is valuable or critical in application, and if suitable nondestructive tests exist.

4. Nondestructive tests offer advantages if there are many possible causes or mechanisms of failure in service. These usually cannot all be evaluated with a reasonable number of *destructive* tests. Since several different *nondestructive* tests may be used in succession on each object, they can cover each of the possible causes for premature service failure.

5. Nondestructive tests usually cost less than destructive tests, in cases where either method can supply adequate information.

6. Nondestructive tests offer particular advantages over destructive tests in maintenance inspection during service. They usually do not require disassembly of units before inspection.

7. Nondestructive tests offer a practical means of assessing the effects of cumulative damage during service.

8. Nondestructive tests, in general, require less preparation of specimens than do destructive tests.

9. Nondestructive tests are usually faster than destructive tests. Conse-

TABLE I.—COMPARATIVE ADVANTAGES AND LIMITATIONS OF DESTRUCTIVE AND NONDESTRUCTIVE TESTS.

DESTRUCTIVE TESTS ADVANTAGES	NONDESTRUCTIVE TESTS LIMITATIONS
1. Tests usually simulate service conditions, consequently tend to measure serviceability.	1. Tests usually involve measurements of properties of no direct significance in service; the correlation between these measurements and serviceability must be proved by other means.
2. Tests are usually quantitative measurements of load for failure or for significant damage, or of life to failure under given loading and environmental conditions.	2. Tests are usually qualitative and rarely quantitative; they do not usually measure load for failure, or life to failure, even indirectly.
3. The correlation between most destructive test measurements and the material properties being measured (particularly under simulated service loading) is usually direct. Hence, most observers may agree upon the results of the test and their significance with respect to serviceability of the material or part.	3. Skilled judgment and test or service experience are usually required to interpret nondestructive test indications, and (where the essential correlation has not been proved or where experience is limited) observers may disagree in evaluating the significance of test indications.

DESTRUCTIVE TESTS LIMITATIONS	NONDESTRUCTIVE TESTS ADVANTAGES
1. Tests are not made on the objects actually used in service; consequently, the correlation between the objects tested and those used in service must be proved by other means.	1. Tests are made directly upon the objects to be used in service; consequently, there is no doubt that tests were made on representative test objects.
2. Tests can be made on only a fraction of the production lot to be used in service; consequently, they have little value when the properties vary greatly, in unpredictable order, from unit to unit.	2. Tests can be made on every unit to be used in service (if economically justified); consequently, they may be used validly even when great differences from unit to unit occur in production lots.
3. Tests often cannot be made on production parts as such and must often be limited to test bars cut from parts, or from special materials processed similarly to simulate the properties of the parts to be used in service. Preparation of the special test specimens may be very costly in some cases. Possible doubt may exist as to whether the test specimen is representative of the part as a whole.	3. Tests are made, if desired, on the entire production part; consequently, the evaluation applies to the part as a whole. Many critical sections of the part may be examined simultaneously or sequentially.
4. A single destructive test measures only one or a few of the properties which may be critical under service conditions, on a given specimen.	4. Many nondestructive tests, each sensitive to different properties of the material or part, may be applied simultaneously or in sequence, to measure as many properties correlated with service performance as may be desired.
5. Destructive tests are not usually applicable to parts in service, unless service is interrupted and the part removed from service, to be destroyed during testing.	5. Nondestructive tests may be applied to parts in service often without interruption of service, and with no loss of serviceable parts.
6. Cumulative change over a period of time cannot be measured on a single unit. If several units of the same lot are tested in succession over a period of time, to establish temporal changes in properties, the proof that the units were initially similar must be established. If the units are used in service and removed from service after various periods of time, it must be proved that each was subject to similar conditions of service, before valid data can be obtained.	6. Nondestructive tests may permit repeated checks of a given unit over a period of time, so that the rate of service damage, and its correlation with service failure, may be established clearly.
7. With parts of very high fabrication costs, the costs of replacing parts destroyed in testing may be prohibitive. Under these conditions, particularly with small production lots, it may not be feasible to make adequate tests.	7. Acceptable parts of very high fabrication costs are not lost in testing; consequently, extensive testing, or repeated testing during service, is feasible.
8. Many destructive tests require extensive machining or preparation of test specimens, and usually require massive, precision testing machines, so that the cost of destructive testing may be very high and the number of samples which can be prepared and tested in any single facility may be severely limited.	8. Little or no specimen preparation is required in many nondestructive tests. Several forms of nondestructive testing equipment are portable and are capable of rapid sorting and testing. The cost of nondestructive tests is in most cases far less than the cost of adequate destructive tests. (Exceptions exist, as, for example, in X-ray inspection of low-fabrication-cost production items, where film and inspection costs may exceed fabrication costs.)
9. The time and man-hour requirements of many destructive tests are very high, contributing to high production costs. Excessive production costs may be incurred if adequate and extensive destructive tests are used in production quality control.	9. Most nondestructive test methods are much more rapid and require far fewer man-hours or actual hours than do typical destructive tests. Consequently, they are suitable for testing large numbers, or all, of the production units, at a cost often less than or comparable to the costs of inspecting destructively only a minor percentage of production lots.

quently, production and servicing delays are minimized. The possibilities of producing large numbers of defective parts successively in production are decreased.

Nondestructive tests differ also from the ordinary measures of *industrial process control.* Industrial process control often provides limits on raw material composition, machine settings, or dimensional tolerances. Statistical methods are often used to increase the value of a limited number of measurements. The purpose of such process controls is to insure consistent high quality in the products of the process. However, some defective units may be produced, even with good process control. Such defects must be detected by other means—for example, by nondestructive testing.

An exception occurs in the case of *proof testing*. Proof testing is an essential nondestructive test. In proof tests, the test objects are loaded to a proof stress (simulating service stresses) at which unsatisfactory specimens should be revealed by their failure. Such proof tests are destructive of *defective* specimens. If properly designed, however, they should be completely *nondestructive* for all sound test objects. Consequently, they could be applied, if desired, to all production specimens, like any other nondestructive test.

It has been true that the testing of structural materials has been primarily *destructive* (of the test samples). This is natural, since many materials tests have been *simulated service tests*. Since the test objects are destroyed, the reliability or value of these destructive tests is critically dependent upon the *similarity of the objects actually tested to those which are placed in service*. The value of destructive tests is also dependent upon the *similarity of the test conditions to the actual service conditions*. The safe use of destructive tests depends upon this *degree of correlation* between the properties of the units tested and those of the units to be placed in service. If this correlation is excellent, the destructive tests may be reliable.

However, the properties of the individual units in a lot or group sometimes vary greatly, often at random. In this case, the correlation between the values obtained in destructive tests and the service performance may be dangerously low. Such variability between units of a group has frequently been used as a basis for rejection of entire production lots. The destructive tests provide no direct means for separating the useful pieces from the dangerous or useless objects in the same group. Thus the good units within such rejected lots are lost also. The cost of these losses may become excessive in some critical fabrication processes.

True *nondestructive* tests, on the other hand, may be applied to those objects which will be later used in service. If desired, all of the units produced may be subjected to nondestructive tests. Consequently, there is no doubt that the unit tested has properties identical to those of the unit to be used in service. *It is actually the same unit.* For this reason, appropriate nondestructive tests may be used with confidence even when the objects within a single lot or group differ greatly in properties among themselves. The useful units may be salvaged for service, even when many defective units may be present in the lot.

It is important to remember, however, that nearly all *nondestructive* test methods measure material properties differing from those which control serviceability. The value and reliability of these nondestructive tests are therefore critically dependent upon the *correlation between the property actually measured* in the nondestructive tests *and the serviceability-controlling properties* to be evaluated.

The validity of this correlation can never be safely assumed. It is open to the same doubt as the corresponding assumption, in destructive testing, that the properties of the few units tested are identical to or representative of those of all other units of the lot. In both cases, the degree of correlation must be established by means other than the tests themselves.

The two dangerous assumptions in testing are:

1. In *destructive* testing:

That the individual specimens tested truly represent the properties of the entire lot.

2. In *nondestructive* testing:

That the specimen properties actually measured do correlate reliably with those properties controlling the serviceability of the test objects.

Neither assumption is necessarily true, for any given case. Therefore, for every specific case, one must prove the underlying assumption to establish the significance of the tests. The assumptions must be proved:

(*a*) for each specific material,
(*b*) in each specific fabricated form,
(*c*) for each specific method of testing, and
(*d*) for each specific service application.

In some situations, the materials in two applications are so similar, or the service conditions are so nearly equivalent, that experience with one may be safely extrapolated to the other case. This, in general, should be done with due caution.

There are two practical ways of proving these basic assumptions. The first way is to accumulate sufficient service experience with the specific material and part under the given service conditions to be sure the assumption is true. The second way is to use destructive and nondestructive tests, each to verify the correlations assumed for the other method. For example, nondestructive tests such as X-rays and magnetic-particle inspection may be used to compare all the units in a lot. In this way, one can establish the similarity within the lot of samples to be tested *destructively* and of the remaining units to be placed in service. Alternatively, destructive physical tests may be used to establish the correlations between the properties actually measured in nondestructive tests and the serviceability of the parts.

For these reasons, it is obvious that nondestructive tests will not entirely supplant destructive tests, nor will the reverse occur. Both types of tests are essential in materials testing. They complement and support each other. Each increases the reliability of the other. Each may provide the essential proof of the basic correlation upon which the success of the other method is critically dependent, for reliable inspection of materials, parts, and structures for service applications.

THE ELEMENTS OF NONDESTRUCTIVE TESTS

Most nondestructive tests depend, for transmission of information concerning the object under test, upon a probing medium. The medium must usually be supplied from an external source. For example, this may be an X-ray tube, a magnetizing coil, an ultrasonic generator, or a spray gun. The medium may be distributed rather generally through the object being inspected, as with a broad X-ray beam. Alternatively, it may be concentrated in a narrow beam, as in ultrasonic testing. The source and type of probing medium must be selected so that its distribution upon the surface or within the test object is *modified by the presence of defects or by variations in the properties being tested*. Often, only a small portion of the incident medium is so affected. For this reason, very sensitive detectors of variations in the medium distribution are required, in order to obtain indications of the presence and nature of defects or variations in properties in the test object. The small variation of the medium in the pickup or detector unit must then be indicated or recorded by sensitive instruments or processes, such as the exposure and development of X-ray film. Finally, the indication or record must be interpreted, usually by a skilled inspector, in terms of the correlated serviceability property.

The five essential elements of most nondestructive tests are:

1. Supplying of a suitable form and distribution of probing medium from an external source to the test object.
2. Modification of the medium distribution within the test object as a result of its discontinuities or other variations in the material properties which correlate with serviceability.
3. Detection of the change in medium distribution or properties by a sensitive detector.
4. Indication or recording of the signal from the detector in a form useful for interpretation.
5. Interpretation of the indication and judgment of the corresponding serviceability of the test object.

The practicality and effectiveness of each proposed test method must be evaluated by a full consideration of each of these essential elements. Some theoretically sound test methods are not practical because no suitable source is available to supply the desired form and distribution of medium required for testing. In other cases, the source is available, but there is no practical means of coupling the source with the specimen so that the probing medium can be transferred to the test object in the desired form. Often, the significant defects or variations in properties in the test object do not influence sufficiently the distribution of the probing medium. In other cases, defects fail to influence the distribution of the medium sufficiently *at the point of detection.* In still other cases, the losses due to scattering or absorption of the medium within the test object are excessive. When this happens, the energy level at the pickup is too low for detection. Or, all too often, the indication of internal flaws or properties may be masked by the larger disturbing indications of surface geometry or of other regions closer to the detector.

The critical feature of most test methods is the detector or pickup. Often the required sensitivity to flaw indications cannot be obtained, particularly in the presence of large disturbing effects emanating directly from the source or from other sources of similar nature. In other cases, coupling the pickup to the test object is difficult. Inefficient information transfer results. Further limitations occur in the selecting of sensitivity and range. High-sensitivity detectors often operate properly over only a narrow range. The ultimate sensitivity of the detector is limited by background disturbances, many of which are unavoidable.

In a few cases, the feasibility of a proposed test may be limited by difficulties in amplifying and indicating or recording the low energy output of the pickup devices. High-gain amplifiers or high-contrast processes often have a certain amount of inherent instability or drift which makes permanent calibration difficult. They may require constant recalibration or monitoring. Some pickup signals are of such nature that they cannot be economically recorded in permanent and useful form. These conditions limit the application of many nondestructive tests.

The final requirement, obviously, is

that the test provide an indication or record that can be interpreted usefully, either in terms of the conditions within the test object or in terms of its serviceability. In some simple cases, the discrimination between acceptable and rejectable objects may be made an automatic function of the pickup signal level. In most cases, where many specimen conditions may contribute to test indications, a skilled inspector is needed. The test indications and the inspector's training must be such as to limit his errors in interpretation to reasonable frequencies of occurrence. The more indefinite and ambiguous the test indication, the less reliable its probable interpretation.

In general, a detectable change in the probing medium must be produced external to the test object, if its defects or properties are to be revealed. It is usually not feasible to introduce sensing units or detectors into identically the same space occupied by the material of the test object, nondestructively. Furthermore, if the purpose of the nondestructive test is to find defects or inhomogeneities within the test object, it is essential that these defects or discontinuities influence the probing medium in some manner different from that of the sound material of the test object. Otherwise, the defective material would be indistinguishable from the sound material.

There exists in nature a variety of forms of force, energy, and matter which can be used as probing media in the space adjacent to or occupied by the test object. Any medium which is significantly influenced by the properties of the test object it is desired to measure may possibly serve as a basis for a nondestructive test. A few common examples of such probing media are:

1. Solid matter, serving as (mechanical contact-making) probes.
2. Fluid (liquid or gaseous) matter, in contact with the test object.
3. Magnetic field energy, in static forms.
4. Electric field energy, in static forms.
5. Electromagnetic field energy, in dynamic, usually oscillatory, forms, including:
    (*a*) Visible light.
    (*b*) Infrared light and heat radiation.
    (*c*) Ultraviolet light and radiation.
    (*d*) Radio frequency electromagnetic waves.
    (*e*) High-frequency electromagnetic waves.
    (*f*) Ultra-high-frequency electromagnetic waves (microwaves).
    (*g*) Gamma rays.
    (*h*) X-rays.
    (*i*) Grenz rays.
    (*j*) Waves from the motion of particles of matter.
6. Mechanical motions of solids, liquid, or gaseous matter (energy of mass motion). These usually correspond to oscillatory or acoustic wave vibrations, including:
    (*a*) Single, steep-fronted waves or blows.
    (*b*) Low-frequency (audible) sound waves.
    (*c*) Ultrasonic (inaudible high-frequency) acoustic waves.
    (*d*) Transport of matter under pressure differences.
    (*e*) Jets or streams of matter flow, such as liquid or gas jets, electron beams in vacuum, ion beams in the mass spectroscope.
    (*f*) Large mass movements (as of solid bodies).
    (*g*) Movements of high-energy particles.
7. Forms of chemical, atomic, and molecular energy, and other latent forms of energy (usually associated with the state of matter), including:
    (*a*) Energy from chemical combinations and dissociations.
    (*b*) Energy from molecular to atomic combinations and dissociations.
    (*c*) Energy from ionization and recombination of electrons with atoms and molecules.
    (*d*) Energy from nuclear fission and recombination reactions.
    (*e*) Latent energy of transformation from solid to liquid and from liquid to gaseous states (latent heat of fusion or of evaporation).
    (*f*) Energy from biological processes.

Nondestructive Test Methods Based Primarily upon Transmission of Energy as the Probing Medium

All methods of nondestructive testing involve some use of energy transmission. This is necessary because, at some point in the process, the information must be transmitted to an observer or actuate an automatic selection device. However, some extremely useful nondestructive test methods depend primarily upon transmission of energy for *probing the material conditions*, as well as for transferring this information to a suitable point of detection outside the volume occupied by the material under inspection (Table II).

TABLE II.—TYPICAL NONDESTRUCTIVE TEST METHODS BASED UPON TRANSMISSION OF ENERGY.

Test Method	Form of Energy Used as Medium	Mechanism of Detection of Material Properties and Discontinuities	Forms of External Test Indications
Optical or visual inspection and other luminous energy tests	Visible light	Reflection, absorption, refraction, or scattering of light, etc.	Visible image, often produced with lenses or other optical aids, etc.
Radiography, fluoroscopy, X-ray gaging, xeroradiography, and other penetrating radiation tests	X-rays, gamma rays, Grenz rays	Absorption, scattering, transmission of rays, etc.	X-ray film images, xerographic images, fluoroscopic screen images, ionization gage indications, crystal or Geiger counting, etc.
Magnetic particle and other magnetic field tests	Magnetic-field energy	Distortion of magnetic field flux, attenuation of field, fringing of flux lines, caused by discontinuities in magnetic permeability, etc.	Finely-divided magnetic particle indications on exposed surfaces of test object, induced emf's in moving coil probes, variations in reluctance of Gauss meters, Hall effects in current-carrying probes, etc.
Electrified particle and other electric field tests	Electric-field energy	Distortion of electric field flux, breakdown of dielectric, corona or radio noise at defects, dielectric constant, dielectric losses, etc.	Spark over or dielectric breakdown, radio noise, capacitance values, leakage currents, ohmic resistance measurement, collection of electrified particles, etc.

As a criterion for selection of test methods in this category, it may be sufficient to note that such transmission of energy (in the form used in the test) could take place in perfect vacuum, without the motion of particles or presence of any form of matter. Electromagnetic fields, either static or dynamic, fall into this class (in those spatial regions where movements of electric charge or magnetic poles are absent).

Static electric and magnetic fields form the basis of many useful tests. Dynamic electromagnetic fields, throughout the wide frequency range now producible, provide a far more extensive base for nondestructive test methods. As a general principle, it may be recognized that the wavelength of oscillatory probing media should be comparable to (within a few orders of magnitude) or smaller than the critical dimensions of discontinuities which they are expected to detect. It is usually difficult to reveal discontinuities with waves whose length is several orders of magnitude larger than the discontinuity itself.

Visual Inspection and Other Luminous Energy Tests:

Luminous energy tests are characterized by the use of visible light to illuminate test objects. These may be scanned by eye or by light-sensitive devices such as photoelectric cells. Ordinary visual inspection and inspection with optical aids, such as telescopes, microscopes, mirrors, and lenses, fall in this class. Tests employing media other than visible light to probe the test objects are not included and are discussed elsewhere in this paper.

Visual observation is naturally the most widely used inspection method. The human eye has excellent visual perception although it is limited in frequency response to wavelengths between 400 and 700 μ. Its response varies considerably throughout this frequency range. It peaks in brightness response at a frequency near 520 to 540 μ. Its acuity and contrast sensitivity decrease rapidly as the energy level of illumination decreases within the visual frequency range. The tendency toward ocular fatigue is accelerated by the presence of glare (brightnesses within the field of view varying by more than 10 to 1), or by efforts to see at low levels of illumination or outside the optimum frequency range (470 to 610 μ).

For critical inspection under other than optimum conditions as indicated above, the attention span of the human observer is limited to reasonable periods of time. For observation at very low light levels (as in fluoroscopy), the human eye should be dark-adapted in advance. The period of intense inspection should be limited to the order of 15 to 30 min at a time, to avoid errors due to fatigue and to deterioration in visual reliability and discrimination.

The maximum visual acuity at high brightness levels exists only for that small portion of the image focused upon the fovea centralis, or "spot of clear vision," near the center of the retina. Here the layer of blood vessels, nerve fibers, and cells above the perceptors (rods and cones) is far thinner than in peripheral regions of the retina. Here also the high brightness color discrimination (frequency response) and visual acuity are at their maximum. Critical inspection, therefore, requires rapid movement of this sharp image area to various points in the inspection field. Complete *detailed* visual inspection is feasible only if each critical area can be scanned by the "spot of clear vision" of the eye.

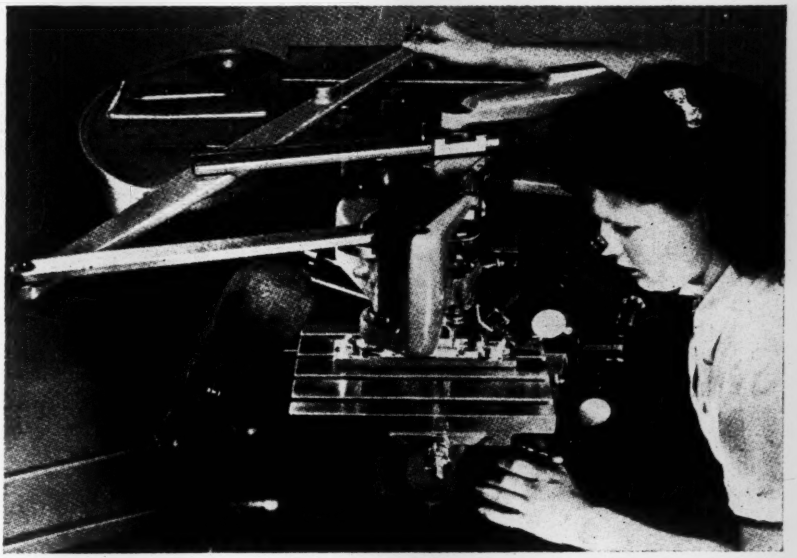


FIG. 7.—Microscopic Control and Inspection of Production Processes. (Courtesy American Optical Co., Scientific Instrument Div., Buffalo, N. Y.)

At low light levels, on the other hand, the peripheral regions of the retina, which are lacking in color discrimination and visual acuity, provide much of the visual sensitivity. Relative motion of the test object and the observer's eye may improve reliability and discrimination in this type of vision.

Optical magnifiers and microscopes provide valuable means of compensating for the limits of visual acuity of the human eye, by enlarging small discontinuities and structural details of materials (Fig. 7). Enlarging projectors and comparators improve viewing conditions for rapid inspection of small precision parts. Industrial (wired) television systems permit observation from a distance or at otherwise inaccessible points in production (as, for example, with radioactive materials). Borescopes permit direct visual inspection of the interior of hollow tubes and of other internal surfaces, under optimum viewing conditions (Fig. 8).

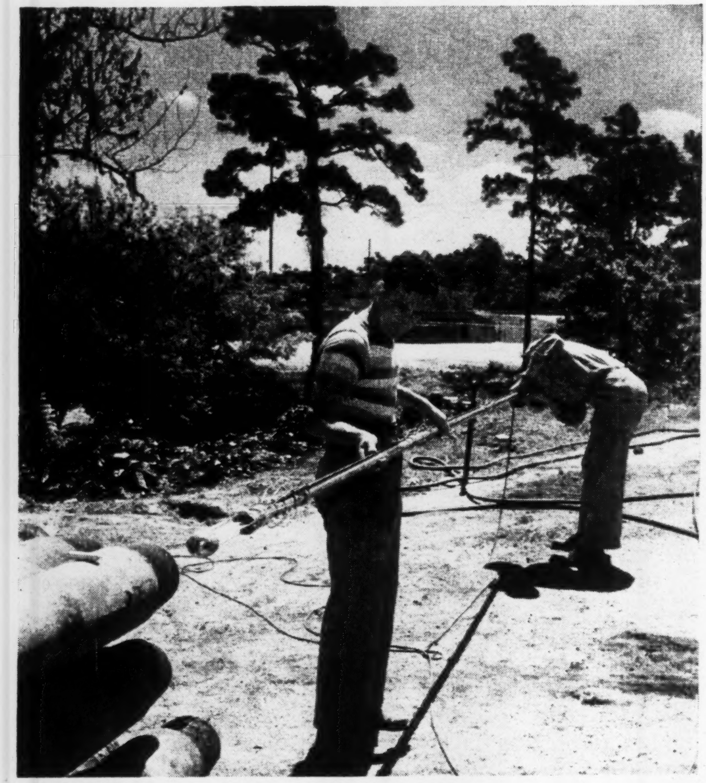


FIG. 8.—Tuboscope Used in Inside Inspection of Oil Well Drill Pipe. (Courtesy Tubular Service and Engineering Co., Houston, Tex.)

Photoelectric and other automatic detection systems have replaced direct visual inspection with automatic nondestructive testing in many industrial applications, such as counting, gaging, color matching, measuring contour and surface roughness, and detecting surface flaws in sheet materials.

Visual inspection and other luminous energy nondestructive tests are the most widely used forms of nondestructive tests in industry. However, their forms, applications, and limitations are so well known that there is little need to describe them further here.

X-ray and Other Penetrating Radiation Tests:

Test methods in which the test objects are subjected to penetrating radiation, such as X-rays or gamma rays, are included under this subject heading. Penetrating radiation tests are characterized by exposure of test objects to beams or fields of penetrating radiations. The intensities of these beams are modified by passage through or reflection from the material and defects in the test objects. The differential absorption of the radiation is a function of the material structure and properties. These include density, mass, thickness, and other properties of the test object. Scatter, internal reflection, diffraction, and production of secondary radiation within the test object introduce additional variables. Sensitive radiation detectors are employed. These include X-ray film, xeroradiographic plates, fluorescent screens, Geiger tubes, and ionization gages. These detectors transform differences in intensity of the visible radiations into visual images or electrical signals.

Long wavelength radiations such as radio waves, microwaves, heat radiation, and light generally fail to penetrate metallic materials sufficiently to serve as useful media for internal inspection. On the other hand the short wavelength electromagnetic radiations, particularly the Grenz rays, X-rays, and gamma rays, penetrate atomic lattices with relative freedom. Such penetrating short wavelength electromagnetic radiations provide a potent tool for internal inspection of materials. Their wavelengths are short with respect to the interatomic spacings in solid materials. Despite their relative ease of transmission through materials, waves in this frequency region are sensitive to material properties and discontinuities. The longer wavelength, low-energy penetrating radiations, such as Grenz rays, are most useful in examining thin layers of dense materials such as metals and alloys. They serve also in the examination of low-density materials such as organic materials, liquids, and gases. The shorter wavelength, high-energy penetrating radiations (such as high-voltage X-rays and gamma rays) are best used for examining the denser materials, such as ferrous and heavy metal alloys, and thick sections.

When electronic X-ray tubes operate with continuously applied and constant values of potential between target and cathode, the frequency (and wavelength) of the resultant X-radiation are related to the accelerating voltage applied to the electron beam. The minimum wavelength (λ_c in Ångström units) (maximum frequency, f_c) limit is given by:

$$\lambda_c = \frac{1}{f_c} = \frac{12.345}{\text{kvp}}$$

where the electron beam accelerating voltage in the X-ray tube is given in "kilovolts peak" (kvp). The major part of the X-ray emission is at greater wavelengths than this minimum or cutoff limit and consists of "white radiation" of many wavelengths.

When X-ray tubes operate self-rectified on alternating current power supplies, each conducting half cycle of current applies a wave of voltage varying from zero to the peak value and back to zero amplitude. The quantity of X-rays produced, and their equivalent wavelength or penetrating power, also change continuously, as a function of the applied voltage, during each conducting half cycle. The result is the production of radiation with a typical penetration approximately equivalent to that of monochromatic radiation produced at a constant voltage of about 59 per cent of the peak voltage applied in the a-c circuit.

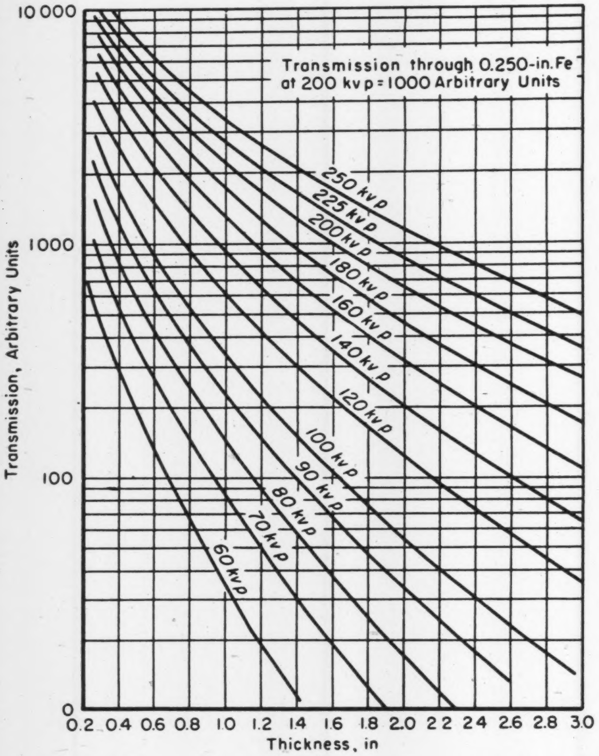
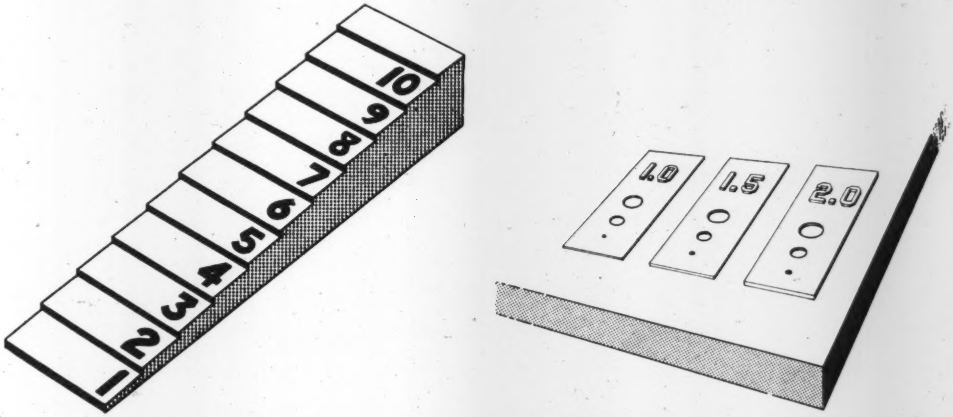


FIG. 9.—X-ray Transmission Curves for 24S Aluminum as Dependent on Material Thickness and Source Kilovolt Peak. (Courtesy H. D. Roop, Los Angeles, Calif.)

The reactions between these penetrating electromagnetic waves and the materials through which they pass may be somewhat complex. For example, the incident beams are absorbed and attenuated as they pass through materials. Their attenuation is a function of material density and thickness. As the primary beam is absorbed in a material, there are produced secondary radiations (of lower energy and longer wavelength) as well as secondary particles, such as electrons. Both the secondary radiations and the secondary particles may have sufficient energies to pass through considerable thicknesses of material. These, in turn, may react with the material to produce tertiary radiations and particles.

With high-energy incident radiation, the secondary radiation tends to be directed in the general orientation of the primary beam. With lower energy incident radiation, and with secondary and subsequent generation radiations, the scatter tends to become more general in all directions. In consequence, the directional properties of beams tend to degenerate as attenuation increases and as low-energy secondaries are produced. In extreme cases, the randomly scattered degenerate radiation may approach or exceed the intensity of the attenuated primary beam. In this case, it becomes more difficult, if not impossible, to produce useful shadow images or radiographs. Special grids or filters are then used to screen out secondary scatter.



(*a*) Aluminum step-wedge penetrameter.

(*b*) One to two per cent penetrameters.

Fig. 10.—Step-Wedge and Penetrameters.

With monochromatic radiation (of a single frequency), the attenuation of the primary beam may be expressed as an exponential function of the mass (or of the thickness and the density) of the material through which it passes. Thus, the primary beam intensity I_x within the material may be written in terms of the incident intensity, I_0, the material density, ρ, and the distance, t, of penetration, as:

$$I_x = I_0 \epsilon^{-\mu\rho t}$$

Here μ is a factor relating X-ray absorption power to the material density, ρ. The logarithm of the transmission ratio, I_x/I_0, is a linear function, for a homogeneous material, of the thickness of material through which the beam has passed:

$$\log_\epsilon(I_x/I_0) = -\mu\rho t$$

Curves for $\log_\epsilon (I_x/I_0)$ plotted as a function of material thickness, t, drawn on semi-log coordinates tend to be straight lines. In practice, however, it is difficult to obtain high-intensity beams of monochromatic radiation. It is also hard to measure the primary beam without errors introduced by secondary radiation. In practical radiography, consequently, the effects of "white" (multiple frequency) primary beams and of secondary radiation produced within the test objects cause deviations from the simple law expressed above. These cannot be ignored. Typical transmission curves for "white" radiation of several different energy distributions, for a typical industrial material, are given in Fig. 9. These curves deviate from linear because of the nonmonochromatic characteristics of the primary beams and because of the very significant contributions of secondary scatter.

The quality (sensitivity) of the radiographic image of a test object is a function of the definition and the contrast in the transmitted beam of radiation. It depends also upon the process by which the invisible beam is made to produce a visible image. The definition is related to the sharpness with which the boundaries of a discontinuity of the test object are revealed in the transmitted beam or the final image.

In homogeneous materials, the large-area contrast may be defined in terms of the minimum differences in the thickness of the test object which can be detected in the transmitted beam. Assume a difference in thickness, Δt, in the total thickness, t, of the test object. Suppose that this thickness increment causes a difference in intensity, ΔI, in the total transmitted beam intensity, I. Then the X-ray beam contrast factor, C_x, may be defined as:

$$C_x = \frac{\Delta I/I}{\Delta t/t} = \frac{\Delta \log I}{\Delta \log t}$$

The intensity of the transmitted beam, I, decreases as the material thickness, t, increases. Therefore, C_x is essentially negative. However, only its absolute value is of interest.

In practice, penetrameters are often used to establish a measure of definition and contrast in X-ray images. Standard penetrameters are fabricated to 2 per cent (or other fractions) of the specimen thickness, of material with the same X-ray absorption. Holes drilled in the penetrameter, with diameters equal to its thickness and multiples of its thickness, provide small-area images for critical viewing (Fig. 10). The penetrameters are placed on the source side of the test object during X-ray exposure. The clarity of the penetrameter images in the over-all X-ray image establishes the "sensitivity" of the radiographs. Two per cent sensitivity (meaning that a penetrameter 2 per cent as thick as the test object is clearly revealed) is a common specification requirement.

Sources of Penetrating Radiation.—Natural sources of penetrating radiation include cosmic rays and naturally radioactive materials, such as radium and the gas radon. Roentgen found that X-rays could be produced when electron beams in vacuum bombarded metallic targets. A readily controllable electronic source of X-rays then became available. With the advent of the Coolidge hot-cathode X-ray tube, the problems of cold-cathode emission in gas tubes were avoided. Practical sealed-off X-ray tubes could be produced. More recent electron-accelerating devices, such as the cyclotron, the betatron, the synchrocyclotron, the Van der Graaff linear accelerator, and their modifications, have provided new electronic sources. These are capable of producing beams with energies equivalent to several hundreds of millions of electron volts. In addition, recent developments in nuclear physics have produced a large number of new radioactive materials. These have a wide range of wavelength characteristics. They provide new, low-cost sources of penetrating radiation.

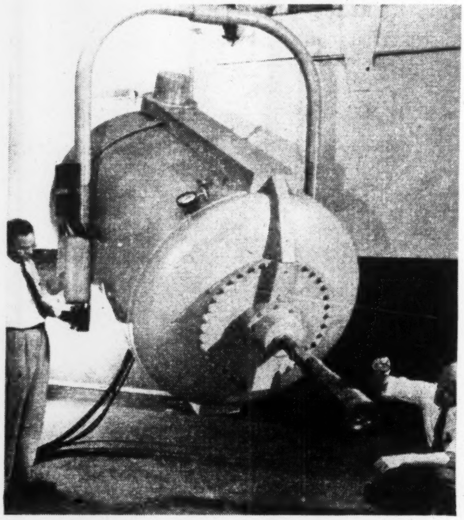


FIG. 11.—Two Million Volt X-ray Equipment Developed by Charleton and Westendorp in the General Electric Research Laboratory. (Courtesy General Electric X-ray Div., Milwaukee, Wis.)

Conventional hot-cathode vacuum X-ray tubes are now manufactured commercially for operation at various peak voltage values in the range from 5 to 2000 kvp (Fig. 11). Continuous beam current ratings are limited, in general, so that the heat dissipation at the anode (target of the electron beam) does not usually exceed about 3 kw.

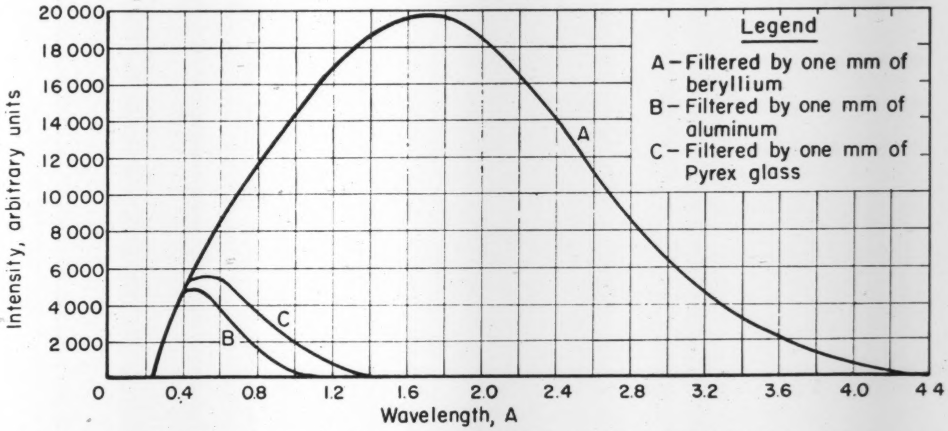


Fig. 12.—Filtration of X-rays in X-ray Port Materials. (Courtesy Machlett Laboratories, Inc., Springdale, Conn.)

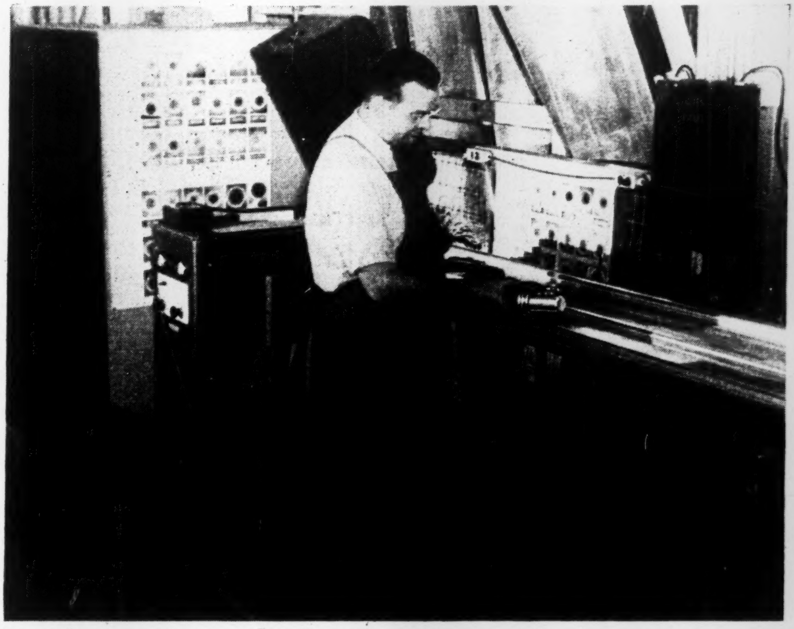


Fig. 13.—Radiographing Spot-Welded Aircraft Tail-Boom Panels in Production Welding Department, with Picker 50-kvp Industrial X-ray Unit. (Courtesy Picker X-ray Corp., New York, N. Y.)

Low-voltage tubes (5 to 50 kvp) often have beam current ratings of 30 to 50 ma (milliamperes). Tubes to operate in the range from 50 to 150 kvp are usually rated for currents of the order of 10 to 15 ma. Tubes rated from 150 to 400 kvp operate with beam currents as low as 5 to 8 ma. Million and multimillion volt tubes have electron beam currents of the order of microamperes.

Each tube includes an electron-emitting cathode. The electron beam is usually focused by means of focusing cups or electrostatic field control rings located near the cathode. The electron beam impinges upon a tungsten (or other heavy metal) insert in the water-cooled copper anode structure. The collision of the high-velocity electrons with the target produces X-rays which are emitted from the surface of the target. Each X-ray tube is provided with a thin-walled or low-absorption X-ray port. The X-rays thus emerge into the ambient atmosphere. The targets are often angled. They present a minimum effective area with respect to the port, yet provide a maximum area for dissipation of heat from the electron beam. The tube ports are usually made with the minimum feasible inherent filtration (absorption of X-rays) for low-voltage applications (Fig. 12). This permits the maximum quantity of X-rays to escape from the tube into the exposure region. Beryllium, a low-density metal, has replaced mica and Lindemann-glass windows for such applications in most modern X-ray tubes which operate below 50 kvp.

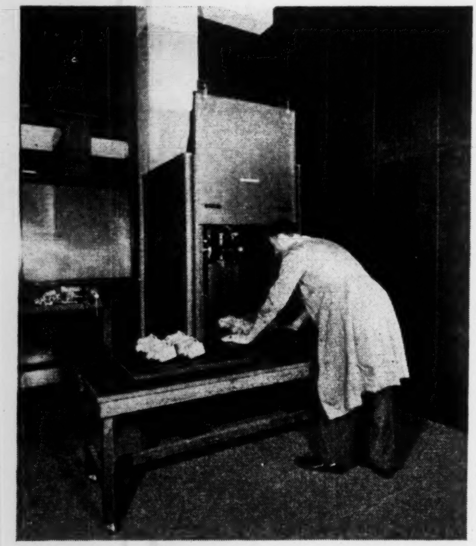


FIG. 14.—150-kvp Industrial X-ray Inspection Installation, Showing Protective, Lead-Lined Hood. (Courtesy Magnaflux Corp. Chicago, Ill.)

Many specially designed X-ray tubes have been developed to meet the requirements of particular applications in industry and medicine. These include fine focal spot tubes (which allow for direct enlargement of X-ray images), tubes with large Roentgen unit X-ray output, tubes with rotating anodes for short, intense exposures, "flash tubes," and others.

Low-voltage X-ray sources (5 to 50 kvp) are used for radiography of thin materials and sheets, spot welds in light alloys, plastics and organic materials, and in X-ray diffraction studies of the structure of materials (Fig. 13). Medium voltage sources (80 to 160 kvp) find extensive use in radiography and fluoroscopy of light alloy parts in the aircraft industry and for general radiography of thin sections of denser materials (Fig. 14). Higher voltage equipment (250 to 400 kvp) is required in radiography of thicker sections of steel and other heavy materials, as well as for radiography of thicker sections of light alloys (Fig. 15). Million and two million volt sources find a wide range of potential high-volume industrial inspection applications in ordnance, heavy ferrous castings, large machined parts, and similar test objects, because the penetrating power of their radiation reduces the exposure times far below those required with lower voltage sources (Fig. 11). Induction accelerators, such as the betatron, provide practical sources of radiation in the 10 to 31 million volt range and have been constructed for op-

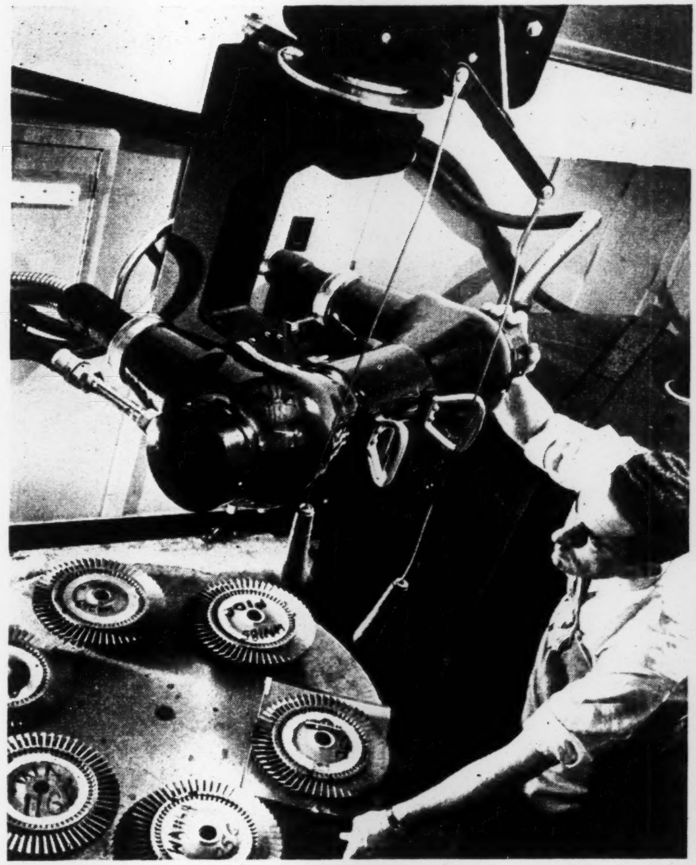


Fig. 15.—X-ray Inspection of Tungsten Alloy Aviation Gas Turbine Wheels with Westinghouse. 250-kv Unit. (Courtesy Westinghouse X-ray Div., Baltimore, Md.)

TABLE III.—THE RADIUM SERIES.

Name	Symbol	Half-Life	Radiations, mev, max		
			Alpha	Beta	Gamma
Radium	Ra 222	1620 yr	4.61	...	0.188
Radon	Rn 222	3.825 days	5.49	...	...
Radium A	Po 210	3.05 min	5.99	...	...
Radium B	Pb 214	26.8 min	...	0.72	0.35
Radium C	Bi 214	19.7 min	...	3.17	2.42
Radium C′	Po 214	1.5×10^{-4} sec	7.7	...	...
Radium C″	Tl 210	1.32 min	...	1.8	...
Radium D	Pb 210	22 yr	...	0.026	0.046
Radium E	Bi 210	5 days	...	1.17	...
Radium F	Po 210	138 days	5.29	...	0.77
Radium G	Pb 206	Stable	...	...	...

TABLE IV.—HARD GAMMA SOURCES.

Isotope	Half-Life	Gamma-Ray Energies, mev
Sodium 24	14.8 hr	2.758; 1.38
Gallium 72	14.3 hr	2.51; 2.21; 1.87; 1.59; and others
Radium 226	1620 yr	2.42; 2.20; 2.09; 1.82; and others
Lanthanum 140	40.4 hr	2.3; 1.65; and others
Antimony 124	60 days	2.04; 1.708; 0.732; and others
Praseodymium 142	19.3 hr	1.74; 0.49; 0.424; an others
Arsenic 76	26.8 hr	1.70; 1.20; 0.55
Barium 131	11.7 hr	1.70; 1.2; 0.50; 0.22
Europium 154	5.4 yr	1.6; 0.40; 0.34; 0.28; and others
Potassium 42	12.4 hr	1.51
Silver 110	270 days	1.48; 0.9; 0.6
Bromine 82	35 hr	1.36; 0.787; 0.465
Cesium 134	2.3 yr	1.35; 0.79; 0.60; 0.57
Copper 64	12.8 hr	1.35
Cobalt 60	5.3 yr	1.33; 1.17
Iron 59	46.3 days	1.30; 1.10
Europium 152	5.3 yr	1.23; 0.162; 0.123
Tantalum 182	113 days	1.22; 1.13; 0.22; 0.15
Rhodium 106	30 sec	1.2; 0.73; 0.51
Osmium 193	32 hr	1.2
Zinc 65	250 days	1.14
Scandium 46	85 days	1.12; 0.88
Rubidium 86	19.5 days	1.08
Zirconium 95	65 days	0.92; 0.73; 0.23
Holmium 166	27 hr	0.92; 0.081
Indium 114	50 days	0.9; 0.186; 0.15
Molybdenum 99	67 hr	0.84; 0.185; 0.77; 0.24

TABLE V.—CLASSIFICATION OF ISOTOPES BY ENERGY OF GAMMA RADIATION.

Greater than 2.0 mev	Half-Life
Radium 226	1620 yr
Antimony 124	60 days
Lanthanum 140	40.4 hr
Sodium 24	14.8 hr
Gallium 72	14.3 hr
Manganese 56	2.6 hr
1.5 to 2.0 mev	**Half Life**
Europium 154	5.4 yr
Silver 110	270 days
Barium 131	11.7 days
Arsenic 76	26.8 hr
Praseodymium 142	19.3 hr
Potassium 42	12.4 hr
1.0 to 1.5 mev	**Half-Life**
Cobalt 60	5.3 yr
Europium 152	5.3 yr
Cesium 134	2.3 yr
Zinc 65	250 days
Tantalum 182	113 days
Scandium 46	85 days
Iron 59	46.3 days
Rubidium 86	195 days
Bromine 82	35 hr
Osmium 193	32 hr
Copper 64	12.8 hr
Rhodium 106	30 sec
0.5 to 1.0 mev	**Half-Life**
Antimony 125	2.7 yr
Polonium 210 (RaF)	138 days
Iridium 192	70 days
Zirconium 95	65 days
Indium 114	50 days
Cadmium 115	43 days
Ruthenium 103	41 days
0.5 to 1.0 mev (cont'd)	**Half Life**
*Niobium 95	35 days
Neodymium 147	11 days
Iodine 131	8 days
Antimony 122	2.8 days
Molybdenum 99	67 hr
Cadmium 115	2.3 days
Samarium 153	47 hr
Holmium 192	27 hr
*Wolfram 187	24.1 hr
Europium 152	9.2 hr
Ruthenium 105	4 hr
0.25 to 0.50 mev	**Half-Life**
Selenium 75	127 days
Hafnium 181	46 days
Mercury 204	44 days
Chromium 51	26.5 days
Germanium 71	11.4 days
Gold 198	2.7 days
Promethium 149	47 hr
Rhodium 105	36.5 hr
Less than 0.25 mev	**Half-Life**
Lead 210 (RaD)	22 yr
Actinium 227	21 yr
Europium 155	1.7 yr
Tin 113	105 days
Technetium 97	92 days
Tellurium 127	90 days
Cerium 141	28 days
Osmium 191	15 days
Cesium 131	9.6 days
Rhenium 186	91 hr
Gold 199	3.3 days
Ruthenium 97	2.8 days
Mercury 197	64 hr
Mercury 197	24 hr

* Formerly columbium and tungsten, respectively.

eration at 100 million volts and higher. Their output is a narrow beam of highly penetrating radiation suitable for the thickest objects feasible for X-ray inspection in industry.

The naturally occurring radioactive materials such as the radium-radon series (Table III) have recently been supplemented by many new pile-produced radioisotopes which produce X-rays or gamma rays suitable for radiography. Radium, radon, cobalt 60, and europium 154, for example, produce hard gamma rays (Table IV), equivalent in penetrating power to those produced by electronic X-ray sources in the million and multimillion volt range. Iridium 192, selenium 75, cesium 134, and hafnium 181, on the other hand, produce softer X-rays (Table V) comparable to those produced in X-ray tubes operating in the range from

100 to 1000 kv. Such radioactive sources have found extensive application in radiography of castings, welds, and structures in the field, and in industrial plants not equipped with appropriate electronic X-ray sources.

Detection and Recording of Penetrating Radiations.—X-rays and other penetrating radiations invisible to the human eye are detected and recorded by means of photographic (X-ray) films and papers, fluorescent screens, xeroradiographic plates, electronic image amplifiers, ionization gages, Geiger and other counting tubes, semiconductor elements, crystal scintillations, and photoelectric detection of fluorescence.

The most widely used and generally most satisfactory method of recording large-area images is by means of X-ray films, which consist of radiation-sensitive emulsions of crystalline silver bromide and gelatin coated heavily on both surfaces of an acetate compound base sheet. Fine-grain films provide high contrast and definition with some sacrifice of exposure speed (Fig. 16). High-speed X-ray films usually have larger grain size and are used with intensifying screens of lead or fluorescent materials to increase their exposure speed and reduce the effects of scattered radiation in many applications. The recently developed Picker-Polaroid-Land films permit processing without chemical solutions in tanks, in about 1 min after completion of exposure. Contrast sensitivities and definition adequate to reveal 2 per cent penetrameters are routinely obtained with X-ray films in many industrial applications. Film radiography is widely used in inspection of welds and castings, critical aircraft and ordnance components, and small parts. Very fine-grain films are necessary in microradiography and X-ray diffraction studies.

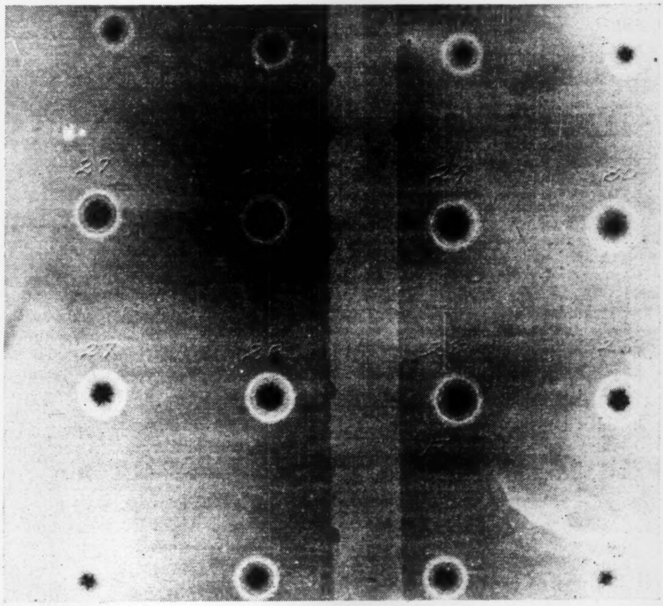


FIG. 16.—Radiograph of Spot Welds in Alclad 24S-T Aluminum Alloy, on Fine-Grain, High-Contrast X-ray Film. (Vertical strip image in center is an X-ray film penetrameter.) (Courtesy Triplett and Barton, Inc., Burbank, Calif.)

Xeroradiography, a dry electroradiographic method of recording X-ray images, is an experimental method not yet commercially available, with potential applications similar to those of X-ray films. In this process, a selenium-coated xeroradiographic plate is electrically charged and then exposed like X-ray film. During exposure, the electrical resistivity of the selenium is modified by the radiation, allowing the electrical charge to leak through where irradiation is most intense. The latent electrostatic image is revealed by dusting the exposed plate with charged particles (as in the Statiflux process) or cascading a two-component developing powder over its surface (Fig. 17). This process has shown itself capable of performance equivalent to that of fine-grain X-ray film throughout the entire range of industrial applications. Unlike X-ray film, however, the sensitive plates may be used repeatedly and do not accumulate fog during prolonged storage in contaminated areas.

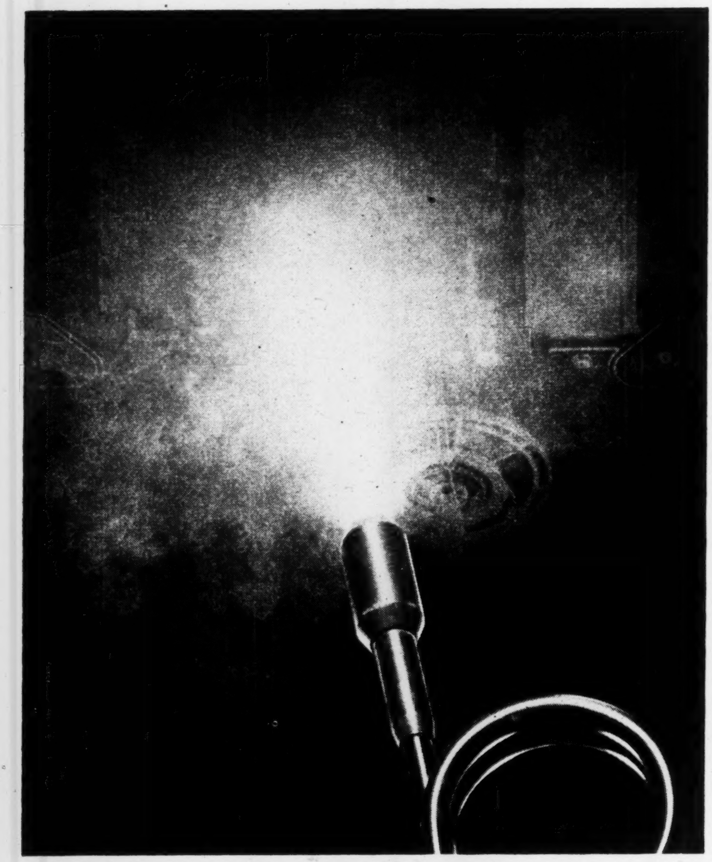


FIG. 17.—White Powder Cloud Development of Electroradiographic Images on Selenium Plate (Courtesy Battelle Memorial Institute, Columbus, Ohio.)

In *fluoroscopy*, the X-ray images are continuously revealed for visual inspection by means of zinc-cadmium-sulfide fluorescent screens. Usually no permanent records are made, although the fluorescent screen images may be photographed (photofluorography) if a permanent image is desired. The fluorescent screens now available lack the high gamma (contrast amplification) inherent in most X-ray films and have larger grain size than films. Their image brightness is lower than the optimum illumination used in viewing films. These limitations reduce the contrast sensitivity and definition of fluoroscopy below the ultimate attainable with radiography, but in many applications it has been shown feasible to attain adequate inspection levels with light-alloy parts with high-brightness fluoroscopy, where the test object can be moved relative to the X-ray source and fluorescent viewing screen. O'Connor and others have recently demonstrated the improvement attainable by use of fine focal-spot sources and direct X-ray enlargement of the images prior to their incidence upon the fluoroscopic screen.

Electronic image amplifiers compensate for the brightness limitations of fluoroscopy and permit viewing from a distance. In presently available commercial form, the X-ray image impinges upon a suitable fluorescing screen, in contact with a photoelectric emitting surface. The photoelectron image is electrostatically intensified and focused upon a smaller diameter fluorescent image screen (Fig. 18). Even after optical enlargement to the full size of the original image, the intensified image conveys more useful information under more suitable viewing conditions than the original image viewed upon a conventional fluoroscopic screen. Conventional industrial television systems have been used in connection with electrostatic image amplifiers and other X-ray image reproduction systems.

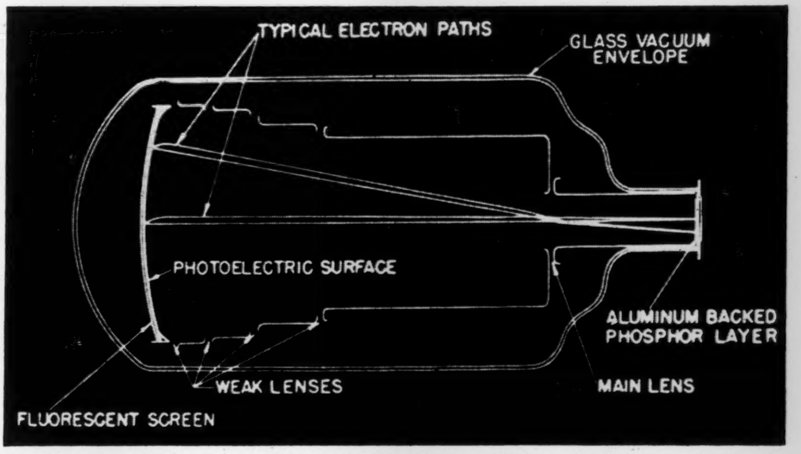
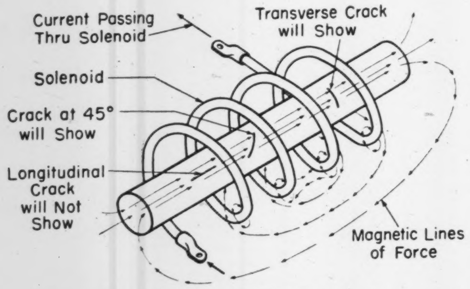
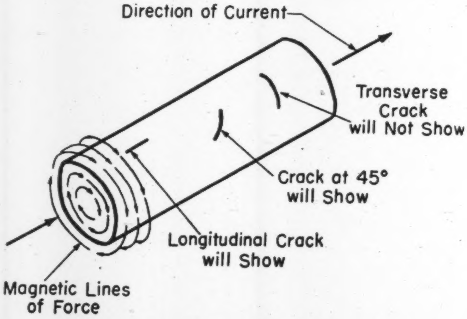


Fig. 18.—Schematic Diagram of Westinghouse Fluorex (Coltman) Electrostatic Brightness Amplifier for Fluoroscopic X-ray Images. (Courtesy Westinghouse X-ray Div., Baltimore, Md.)

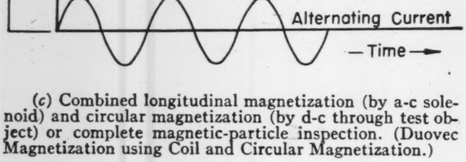
Ionization gages and Geiger counters detect X-rays because of the abilities of penetrating radiation to ionize air and other gases. The ions produced during irradiation of detection chambers produce electrical signals suitable for revealing the intensity of irradiation at the detector locations. Such devices find application in X-ray gaging and radiation monitoring, but because of their relatively large size (as compared with the resolution of X-ray films) are seldom suitable for revealing the detail in X-ray images. The combination of fluorescent screens or phosphors with electronic photomultiplier tubes have provided altenative systems with sensitivities and applications comparable to those developed with ionization gages and counters.


Current Passing
Thru Solenoid
Transverse Crack
will Show
Solenoid
Crack at 45°
will Show
Longitudinal
Crack
will Not
Show
Magnetic Lines
of Force

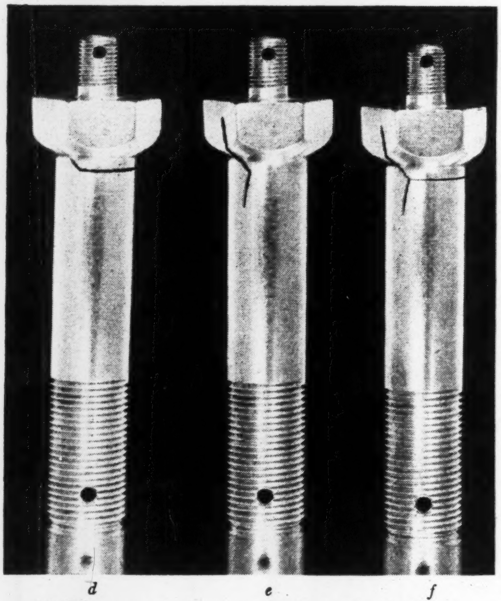
(*a*) Longitudinal magnetization by passing current through solenoid surrounding test object in magnetic-praticle inspection.


Direction of Current
Transverse
Crack
will Not Show
Crack at 45°
will Show
Longitudinal Crack
will Show
Magnetic Lines
of Force

(*b*) Circular magnetization by passing current through test object in magnetic-particle inspection.


ac
dc
dc
ac
Direct Current
Alternating Current
—Time→

(*c*) Combined longitudinal magnetization (by a-c solenoid) and circular magnetization (by d-c through test object) or complete magnetic-particle inspection. (Duovec Magnetization using Coil and Circular Magnetization.)



(*d*) Transverse crack as revealed by longitudinal magnetization.

(*e*) Longitudinal crack as revealed by circular magnetization.

(*f*) Complete crack pattern in same test object as revealed by combined longitudinal and circular magnetization.

FIG. 19.—Methods of Magnetization and Defects Revealed in Magnuflux Magnetic-Particle Inspection of Aircraft Part. (Courtesy Magnaflux Corp., Chicago, Ill.)

Scintillations in crystals and fluorescent liquids, in combination with photoelectric detectors such as the photomultiplier tube, have provided X-ray counters and intensity gages suitable for certain applications. And *semiconductor* elements, such as the cadmium sulfide detector, take advantage of the ability of X-rays to modify their electrical resistivity, to provide electrical signals corresponding to X-ray intensity. Their relatively smaller size than the other counters and gages permits better resolution of X-ray image intensity distributions, but they do not yet match films and screens in definition of image.

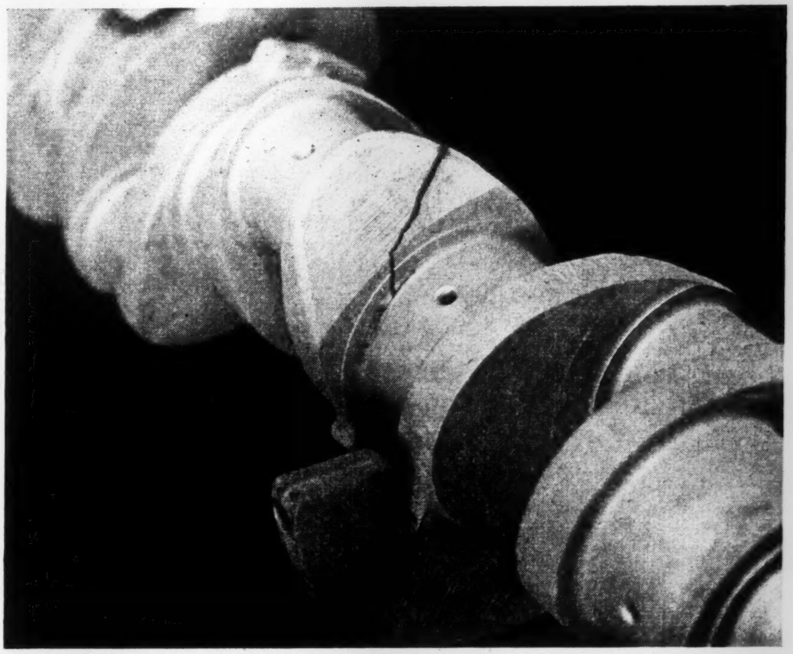
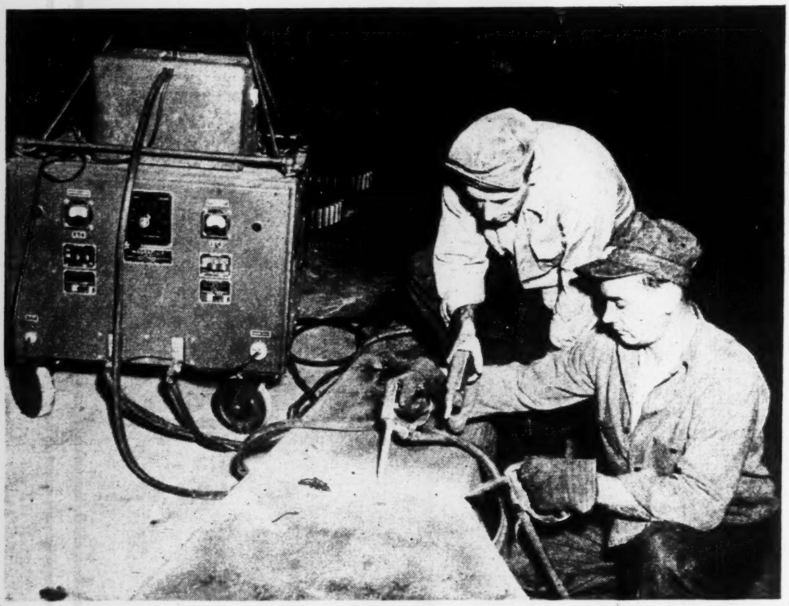


FIG. 20.—Magnaflux Dry Magnetic-Particle Indication of Crack in Crankshaft. (Courtesy Ferro-Spec Laboratories, Los Angeles, Calif.)

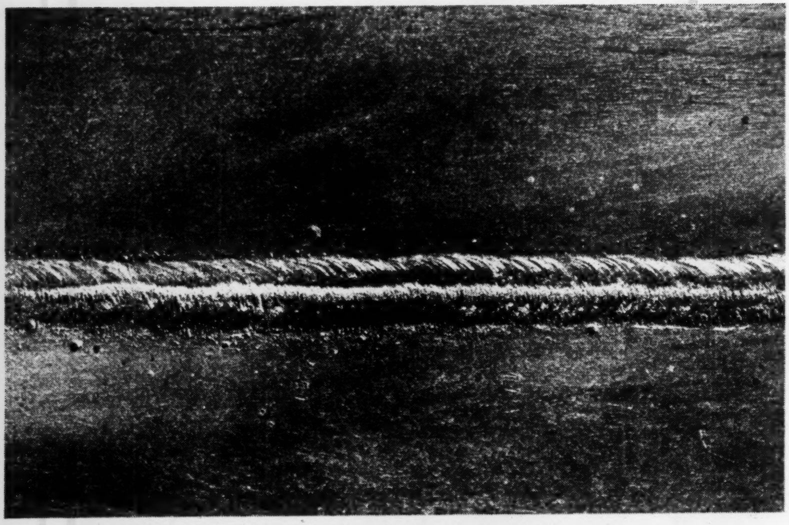
Magnetic Particle and Other Static Magnetic Field Tests:

Test methods in which magnetic fields are used as the medium with which to probe the test object (and not the associated effects such as electromagnetic induction or flow of electrical currents) are classified as magnetic field tests. Static magnetic field tests are generally limited in application to ferromagnetic materials, such as iron or steel, whose magnetic permeability varies greatly from that of air or vacuum. The probing magnetic field used in the test may be measured in terms of several different properties, including permeability, remanence, coercive force, flux density, residual flux, leakage flux, and stored magnetic energy. However, since it would be difficult to introduce probes within most test objects, most practical detectors operate in the magnetic leakage field just outside the surface of the test object.

The test objects may be magnetized by placing them within solenoids carrying electrical currents, by passing electrical currents through the material of the test object, by placing the object between the poles of externally excited magnetizing yokes, and by combinations of these methods. The method of magnetization must be selected so as to establish lines of magnetic flux transverse to the possible direction of discontinuities in the test object, if these are to be revealed (Fig. 19). For surface inspection, alternating-current excitation may suffice, but for detection of discontinuities below the surface, direct current, d-c surge, rectified half-wave a-c, and similar magnetization methods may be preferable because of the "skin effects" which limit the penetration of rapidly varying magnetic fields.

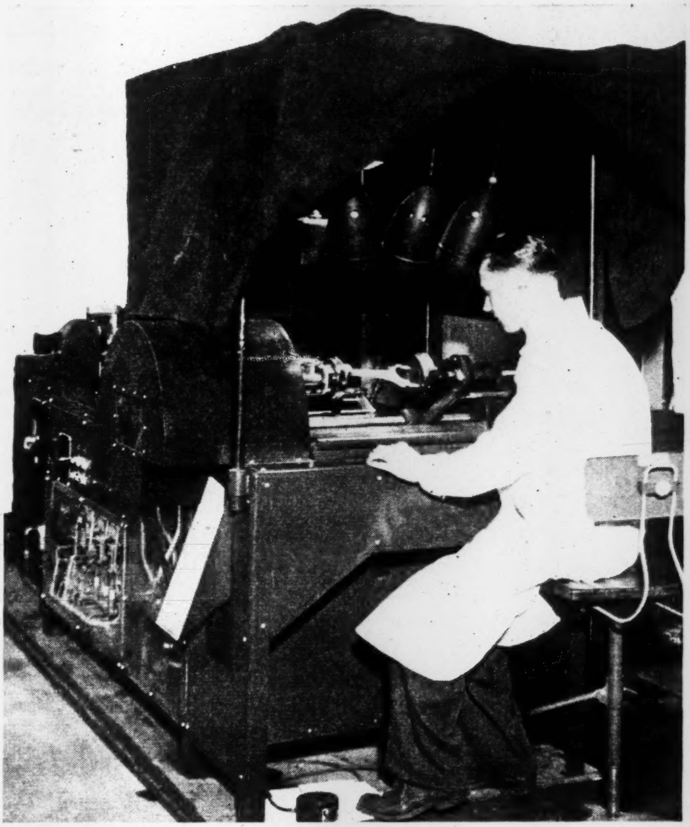


(*a*) Inspection.

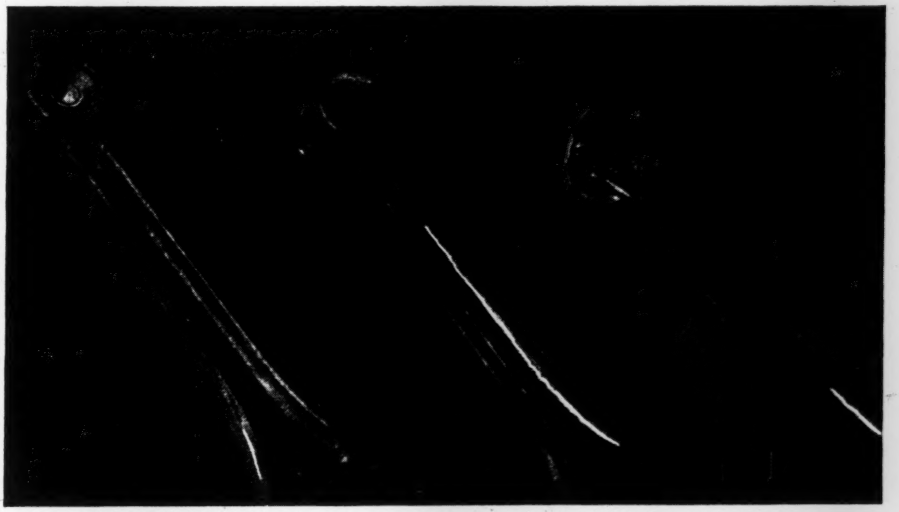


(*b*) Indications of subsurface defect in fusion weld.

FIG. 21.—Magnetic-Particle Inspection of Welds in Fabricated Steel Structural Member. (Courtesy Magnaflux Corp., Chicago, Ill.)



(*a*) Automatic Magnaflux handling and magnetizing equipment.



(*b*) Magnaglo fluorescent wet magnetic-particle indications of defects.

Fig. 22.—Magnaglo Wet Fluorescent Magnetic-Particle Inspection of Connecting Rods. (Courtesy Magnaflux Corp., Chicago, Ill.)

The most widely useful and sensitive method of detection of discontinuities in magnetic field inspection is by means of the *magnetic particle* (*Magnaflux*) method. These finely divided, lubricated, ferromagnetic particles tend to align themselves on the surface of the test object over discontinuities which produce surface leakage magnetic fields (Fig. 20). Their distinctive colors, or fluorescent coatings reveal their indications clearly and show the location, shape, and extent of the discontinuities with remarkable sensitivity. For rough castings, welds, and some field-inspection applications, dry magnetic powders may be applied with an air gun or other applicator, for optimum resolution of surface and subsurface defects (Fig. 21). For production inspection of finished machined parts, suspensions of the indicator particles in suitable liquid media provide an optimum means of application and greatest sensitivity of indications. Automatic machines for handling and magnetizing the parts, applying the magnetic particle indicators, and displaying the parts for inspection have been developed for large production applications (Fig. 22). Today the magnetic-particle inspection method exceeds by far, in number of installations, the number of X-ray units in service. It finds application in production inspection of machined parts for automotive, aircraft, railroad, and many other industries; for field inspection of welds and castings, pipe lines, oil well drill pipe and sucker rods; for service inspections for fatigue and other fractures in the railroad, petroleum, air transportation, and many other fields.

Other methods of detection of magnetic field discontinuities include *induction pickup coils*, whose relative motion through the leakage magnetic field induces varying flux conditions within coils having many turns. These electromotive force signals are electronically amplified and actuate visual or auditory indicators or produce graphic records. *Permeance pickup* methods include methods in which a permeable core material in the pickup coil is magnetized by the leakage magnetic field, changing the impedance of the pickup coil to alternating-current excitation from an external source. Such permeance methods have found applications in gaging the thickness of coatings over magnetic base materials. Signals from electrical detection coils have been successfully applied in the facsimile recording of the magnetic discontinuities revealed on the internal surface of gun tubes and other special applications.

Electrified-Particle and Other Electrostatic Field Tests:

A static electric field is used as the medium with which to probe the test object, in electric field tests. Since it is generally impossible to establish significant electric field gradients in metallic conducting materials (in the absence of heavy electric currents), such tests are suited generally only to dielectric or insulating materials. They find particular application in the evaluation of electrical insulating materials, glass, ceramics, porcelain enamels, and other nonmetallic materials. The electric field patterns and discontinuities may be revealed by the use of electrified particles or electrometers, or by electric circuit measurements of the dielectric properties or breakdown of the test object.

The dielectric materials under test may be subjected to electric fields by spraying their surfaces with electrostatically charged particles, by placing them between electrodes connected to external sources of electrical potential, or by inserting them in high-voltage, low-current circuits suitable for measurement of charging or leakage currents. The latter methods are widely used in conventional tests of high-voltage electric power equipment. The former method has found wide application possibilities in the ceramic industry, in examination for cracks in glass, ceramics, and glazes or ceramic coatings.

The most sensitive and useful method of detecting local discontinuities caused by cracks in dielectric materials and coatings is the use of electrified calcium carbonate particles charged by triboelectrification when sprayed through rubber nozzles in an air gun ("Statiflux"). These finely-divided electrified particles have high mobility and great sensitivity to local surface field conditions and to the presence of sources of electrons. Such

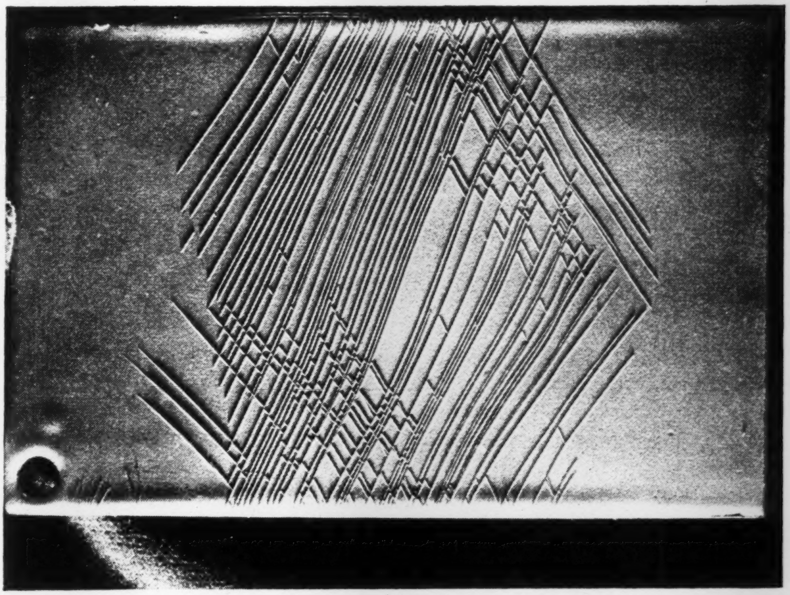


FIG. 23.—Statiflux Indications of Cracks in Porcelain Enamel.

(Note that cracks occur perpendicular to direction of stress. The secondary stress cracks do not cross the original stress. This determined the sequence in which failure stresses were applied.) (Courtesy Magnaflux Corp., Chicago, Ill.)

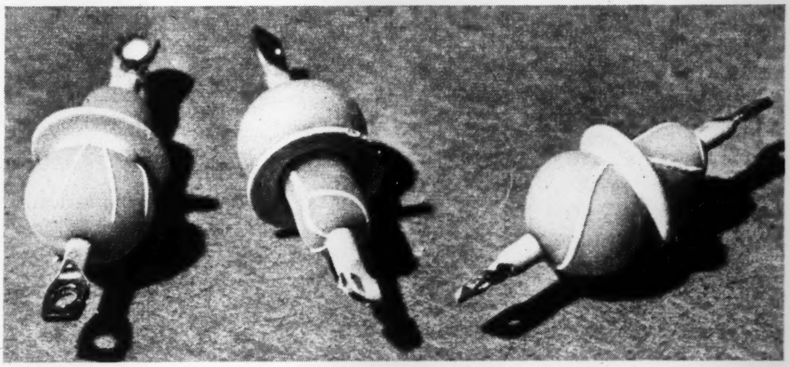


FIG. 24.—Statiflux Indications of Cracks in Typical Glass-to-Metal Bushings (about $\frac{1}{2}$-in. in length) Used in Electronic Equipment. (Seals cracked by improper soldering procedures.) (Courtesy Magnaflux Corp., Chicago, Ill.)

sources of electrons may be provided from the base metallic materials in porcelain-coated sheets, or by use of a liquid penetrant in cracks in ceramic or dielectric materials such as glass. These electrified particles collect over the dielectric discontinuities very much as the magnetic particles collect over cracks and discontinuities in ferromagnetic materials. The technique is so sensitive that fine cracks, invisible to the eye, may be revealed by remarkably high build-ups of the electrified-powder indicator (Fig. 23). In addition to the detection of cracks in ceramic materials, this method finds an extremely useful application in the examination of parts such as electrical bushings, where it reveals defects not detectable by other electrical test methods (Fig. 24).

TABLE VI.—TYPICAL NONDESTRUCTIVE TEST METHODS BASED PRIMARILY UPON TRANSPORT OF MATTER.

Test Method	Form of Matter Used as Medium	Mechanism of Detection of Material Properties and Discontinuities	Forms of External Test Indications
Mechanical Calipering and other dimensional gaging tests of exposed surfaces of test objects.	Solid steel or alloy probes, electric contacts, energy fields, etc.	Movement stops upon contact with surface of test object, or electrical contact, valve effect, etc.	Caliper setting, micrometer reading, visual examination of spacing, "Go" or "No Go" feel of probe, electrical indications, air pressure indications, etc.
Leak test with fluid under pressure	Water, oil, dyes, liquids, (with low viscosities and surface tensions), radioactive liquids, halogens, air, helium, natural gas, hydrogen, steam, halogen vapors, radioactive gases, etc.	Fluid penetrates discontinuities in walls of test object, under hydrostatic pressure, is detectable at an accessible surface	Visible jets or wetting, attraction and binding of powders with good visibility, fluorescence under ultraviolet light, etc., radioactive indications, positive ion detection, bubbles forming in immersion liquid, mass spectroscope indications, radioactive emanations detected, halogen vapor detected by positive ions, etc.
Penetration or leak test with low surface tension liquids	Kerosine, oils, water, with wetting agents, etc.	Fluid penetrates discontinuities open to exposed surface of test object	After surface cleaning, trapped liquid penetrants seep out and spread over surface near defects, with visible wetting, attraction of powder pigments, fluorescence, radioactive emanations, evaporation, positive ion detection of halogens, etc.
Penetration test with low surface tension liquids carrying solid particles in suspensions	Kerosine, oils, water with wetting agents, etc., with solid particles in suspension	Fluid penetrates discontinuities, filtering particles of solids out on surface at defects	Filtered particles on surface visible, or fluorescing under ultraviolet light, radioactive emanations, etc.
Brittle lacquer tests	Brittle lacquer	Elongation of base material cracks lacquer bonded to surface	Cracks (often dyed) in brittle lacquer coating

NONDESTRUCTIVE TEST METHODS BASED PRIMARILY UPON TRANSPORT OF MATTER AS THE PROBING MEDIUM

All movements of matter involve some energy transfer, if only to supply the frictional losses of such motion. However, in many nondestructive test methods whose probing medium is transport of matter, the energy requirements are negligible (Table VI). No special external power sources are required in these tests.

Such tests as depend primarily upon transport of matter for their probing medium have one basic limitation in common. In the gross sense, two kinds of matter, or two bodies, cannot occupy exactly the same space at the same time. Water will not pass through solid steel walls which have no openings or passageways. The rate of transport of gases through solid, nonporous bodies is almost infinitely slower than in free space. For these reasons, nondestructive tests based primarily upon transport of matter are only suitable, in general, for inspection of accessible surfaces of test objects.

There must exist open space, or a passageway, for the probing medium to reach the surfaces to be inspected. In general, the probing medium will not penetrate beyond these surfaces. It stops its advance when it contacts the solid material of the test object. It may, of course, advance through any cracks, channels, or passageways into the material of the test object—but only so far as those openings extend. This behavior is quite unlike that of penetrating radiations, such as X-rays. And it differs considerably from that of high-energy particles, such as neutrons, or of ultrasonic mechanical vibrations, which can penetrate deeply into materials.

Tests dependent primarily upon transport of matter for their probing medium are of three general classes. The first class is that in which solid probes are used to detect the surface of the test objects, as in *mechanical calipering and gaging*. The second involves the use of fluids, usually under externally applied static pressure, in *pressure and leak tests*. The third involves the use of liquids, usually acting only under surface tension and capillary forces, in *liquid-penetrant testing*. In most nondestructive tests, these media apply negligible stress to the test objects. However, in a special class of *proof tests*, the solid, liquid, or gaseous medium applies *stress to the test object*. These stresses are assumed to be harmless to good test objects. They are expected, however, to reveal defective test objects or materials by causing them to distort or fail under the proof stress. Each of these general types of tests is discussed in more detail in the balance of this section of the paper.

Mechanical Caliper or Other Dimensional Gaging Tests:

Mechanical calipering or gaging tests are characterized by measurements through probing media of the dimensions or position of surfaces of test objects. Ordinary manual calipering or gaging instruments and operations are typical, but devices which carry out such measurements by other means or included also. In most cases, the method involves a means of detecting dimensional differences quickly and sensitively, often with automatic indication or sorting of acceptable and rejectable articles.

Just as nondestructive tests based on transmission of luminous energy are an extension of the human sense and skill of *seeing*, so mechanical calipering or gaging tests are an extension of the human sense of *touch or feeling*. In fact, a skilled inspector can often do a remarkably good job of estimating surface finish by touching the object with his fingers. A mechanic with a highly developed sense of "feel" can readily detect a difference in contact by dimensional changes as small as 0.00025 in. Many mechanical gaging instruments, such as "Go-No Go" gages, depend upon the operator to detect by feel the reaction of the test object upon the gage. More elaborate and more precise instruments require the use of the observer's eye to read vernier scales or indicators. Modern instruments of great sensitivity or precision often resort to all the basic principles of nondestructive testing, and use electrical contacts, magnetic field detection, capacitance micrometers, penetrating radiations or particles, flow of liquid or gaseous matter, or other techniques to sense and transmit information in mechanical gaging. Thus, sensitive automatic calipering or gaging most often becomes a true nondestructive testing method, independent of the operator's sensory sensitivity or skills. And like nondestructive tests for other material properties, many modern sensitive gages use electronic circuits to amplify, compare, and evaluate the gage measurements.

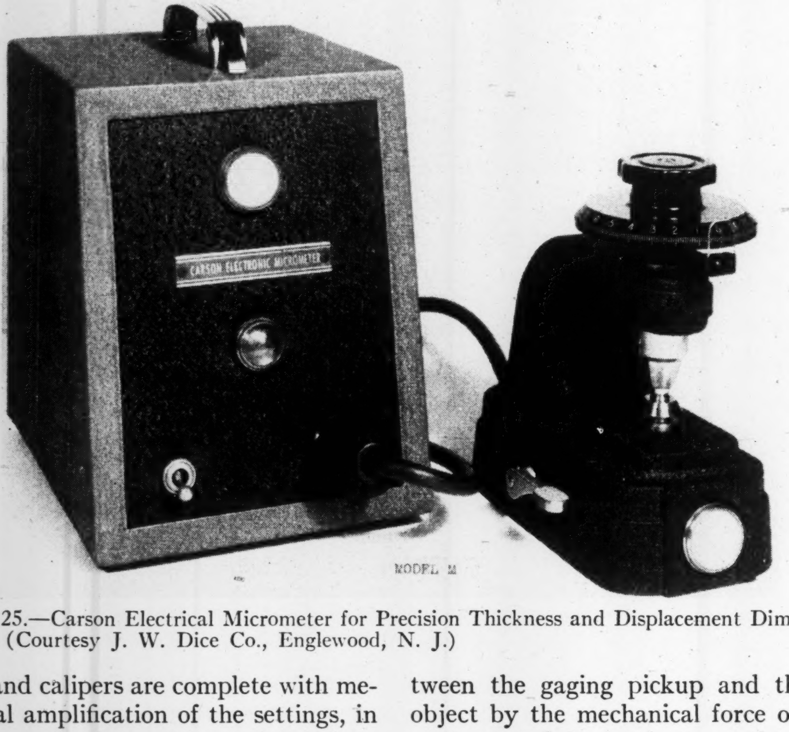


FIG. 25.—Carson Electrical Micrometer for Precision Thickness and Displacement Dimensional Gaging. (Courtesy J. W. Dice Co., Englewood, N. J.)

A large complement of simple *mechanical comparison gages* exists and is well known to every production engineer, mechanic, and tool room attendant. These include linear rules and scales, angle protractors, dividers, calipers with and without vernier adjustments, radius gages, surface gages, and so on. Many precision gages and calipers are complete with mechanical amplification of the settings, in the form of micrometers and verniers. For repetitive measurements of the same dimensions in production, fixed plug, ring, snap, and other forms of gages exist. Precision gage blocks are available to check these fixed gages. Dual fixed gages, set to the upper and lower tolerance limits in production, often serve as "Go-No Go" gages in industrial quality control measurements. More elaborate mechanical displacement amplifiers, in the forms of rack and pinion units and trains of gears, are used in precision dial gages and indicators. Thread gages of various types measure the numerous critical parameters of threaded connections, often by ease of fit or by tolerance limits. These types of mechanical gages are well described in the literature and are well known in industry, so no further discussion of them will be included here.

Each of the simple mechanical gages mentioned above detects contact between the gaging pickup and the test object by the mechanical force or pressure exerted by each upon the other. This is not essential in mechanical gaging. Other methods can sense mechanical contact without the application of sensible force. In cases where it is essential to gage the dimensions of hollow objects with very thin, flexible walls, such as altimeter capsules, it is undesirable to exert any significant force whatsoever upon the test object.

The *electrical micrometer* (Fig. 25) was devised for just this type of measurement, but it has proved its value in many other precision measurements. Contact between the micrometer spindle and the test object surface is detected by means of the flow of a minute electric current across the closed contact. With this device, measurements may be reproduced to a few microinches—an improvement of the order of ten times or so over conventional micrometers depending upon force as a response to contact.

An intermediate approach to this principle is applied in several other mechanical gages. For example, the use of microswitches, which may be actuated with very light mechanical forces, as limit switches in many industrial electromechanical devices is typical. In these applications, an intermediate mechanical lever or amplifier detects contact with the test object by pressure and is bent or displaced to open a sensitive electrical contact operating in a similar low-voltage, low-current electronic detector circuit.

Several modern gages and comparators use a highly accurate "reed" mechanism as the contact-sensing member. When the floating spindle of the gage is moved by contact with the test object, the reed is caused to bend. The bending movement is amplified through extension arms to break an electric circuit which controls signal lights or other indicators.

The *capacitance micrometer method* permits gaging without physical contact with the test object. This is basically an electric field nondestructive test method. It takes advantage of the fact that the electrical capacitance between separated conductors is an inverse function of the distance between them. Indications of microinch sensitivity have been obtained on laboratory instruments based on this principle.

An analogous principle, using a form of magnetic field nondestructive testing, has been applied in various forms of the *inductance micrometer*. With ferromagnetic test objects, the surface of the test object may be used as the movable armature of a magnetic circuit with variable air gaps. Since the inductance of coils wound upon such a variable reluctance magnetic core varies rapidly with air gap spacing, this method also provides a very sensitive test. It has been applied, for example, in commercial instruments designed to measure the thickness of nonmagnetic coatings on ferromagnetic base materials, or the thickness of magnetic coatings on nonmagnetic bases.

The *linear differential transformer* provides an electromagnetic induction nondestructive test method applicable to mechanical gaging. The microformer consists of a small, movable iron core sliding within a cylinder upon which are wound three coils. The central coil is excited with alternating current from an oscillator. It serves as the primary of a transformer. The two identical outer coils serve as balanced secondary windings. These are connected in series opposition. As the iron core moves from its central reference position, the voltage induced in one secondary coil is increased, while that in the other decreases. The net output signal, of the order of 6 microvolts per microinch displacement, may be readily amplified to provide a large output proportional to the displacement of the iron core. Since the cores are exceedingly small (in microformers designed for small displacements), they may touch the surface of the test object while exerting negligible force. A large number of commercial instruments and servomechanisms now employ such linear differential transformers to detect mechanical displacements with great sensitivity and reproducibility.

Another gage consists of a *vacuum tube* whose output current is controlled by means of a *movable control grid*. The movable control grid, as it approaches the cathode, controls the flow of electrons, just as varying voltages applied to the grid circuits control the plate current in conventional electronic amplifiers. In this way, mechanical displacements are converted into electronic signals.

The electrical *wire resistance strain gage* provides another means of converting mechanical displacements into electrical signals. The commercial strain gage has a gage constant of about 2.0; that is, the fractional change in electrical resistance is twice as large as the fractional change in length which produced it. Two such gages mounted on a flexible member responding to displacement of the surface of the test object provide one arm of a Wheatstone bridge. The balance of the Wheatstone bridge, the source oscillator, and electronic amplifiers can be located in a separate unit. Measurements to microinch sensitivities are feasible with this method.

An alternative method uses *unbonded wire resistance strain gages*. Here the resistance wires extend between pegs, one set of which is fixed and the other set of which moves with the surface of the test object. This method has been applied in the aircraft industry for rapid elongation measurements.

The operation of a *magnetic field gage* designed to measure the thickness of nickel coatings on nonmagnetic base materials, or of nonmagnetic coatings on iron or steel, is based upon the magnetic attraction of a small permanent magnet to the coating material being measured or its backing. With annealed nickel coatings, the attractive force between the bar magnet and the nickel coating is practically linearly proportional to the thickness of the coating.

Nonmagnetic coatings on iron or steel interpose the equivalent of an air gap between the permanent magnet and the ferromagnetic base material. The greater the thickness of this intervening layer, the less the attractive force on the magnet.

The operation of *electromagnetic induction micrometers* for measuring the thickness of insulating coatings on conducting nonmagnetic base materials is based upon the electromagnetic inductance effect which the covered base metal has on the probe coil. The oscillating current flowing in the inductor probe induces eddy currents in the base metal. The intensity of these eddy currents varies with the distance between the probe coil and the base metal. The closer the probe to the conducting base metal, the greater the eddy current intensity. The test object serves as a short-circuited secondary of a transformer, of which the probe coil is the primary winding. The eddy currents produce a change in the effective inductance of the probe coil. This causes a change in the frequency of the oscillator to which the probe is connected.

Two other methods of detecting mechanical displacements have received little recognition in mechanical gaging, since both are primarily suited to dynamic, rather than to static, measurements. The first is the *piezoelectric pickup*, such as is commonly used in phonograph pickups. This type of pickup is used in surface-roughness-measuring instruments. Piezoelectric bimorphs of high sensitivity have been developed; under suitable conditions, these might be modified to serve in gaging. The second is the *magnetostrictive pickup* which, to date, has primarily been used only in sonar (underwater sound ranging and detection) reception. Nickel, which is negatively magnetostrictive, contracts when magnetized by passing an electric current through a magnetizing coil surrounding it. If it is stressed so as to change its length, it induces an emf in its magnetizing coil. Thus, it could be used to record mechanical displacements as well.

One other basic principle of nondestructive testing has been well developed for mechanical gaging. It depends upon the flow of a fluid as its medium of detecting the location of the surface of the test object. For example, *air gages* are quite simple. Air under a low pressure head is allowed to escape through an orifice. The orifice is actually the space between the gaging head and the surface of the test object. The rate of escape of air is a measure of this distance. The rate of air escape is metered with another orifice associated with the air supply unit. The pressure drop across this metering orifice may be measured with a water manometer. The air gage provides remarkable sensitivity and amplification of the displacement between the gage head and the work surface. It measures the actual dimensional variations with precision adequate for narrow tolerance production. Measurements can be carried out continuously over a surface, such as the inside or outside diameters or tubes or shafts.

A unique *vacuum cup gage* was used to measure sheet thicknesses and the strength of bonding of thin sheets to base materials. The cup was placed over the sheet, and partial vacuum drawn within the cup. The deflection of the sheet was detected with a sensitive dial indicator.

Nearly all of the preceding nondestructive gaging methods could be applied to the simultaneous gaging of many different dimensions of test objects. The same methods of multiple gaging may be applied in succession to test objects of the same series, to sort and classify parts by dimensional groups. In addition to classifying the useful units into dimensional classes, the out-of-tolerance units can be automatically rejected by such devices.

Fluid Pressure and Leak Tests:

Pressure and leak tests employ fluids under pressure to apply proof stress to test objects or to reveal defects and discontinuities by the flow of fluids through them. Hydrostatic proof tests may be nondestructive of acceptable test objects, even though defective units may fail under their applied stresses. Leaks through container walls may produce visible indications, loss of pressure, or other identifying indications, such as gas bubbles visible when the object is immersed in water during gas pressure tests.

Hydrostatic *proof* tests are commonly applied to pressure vessels and seam-welded pipe for high-pressure gas lines at the time of their fabrication. More recently, entire sections of high-pressure gas lines between valves or compressor stations have been subjected to similar hydrostatic pressure tests after installation, prior to use in service, to avoid the disastrous explosions which can result when such pipe lines fail in service. In addition to proof testing, pipes have also been tested by filling them with compressed air under pressure and observing any decreases in pressure resulting from leaks.

Pressure *leak* tests have found many applications and new detection methods have been developed. It is common practice to immerse pressure containers under water and fill them with gas or air under pressure, so that leaks can be detected by observing if bubbles of gas escape. Viscous fluids, such as soap solutions, are employed where the escaping gas produces bubbles in the surface films. Fluorescent liquids, similar to those used in fluorescent-penetrant tests, may be used with smaller objects as the fluid for hydrostatic-pressure leak tests. The brilliant fluorescence of such fluids, leaking through the container walls, makes inspection with ultraviolet light sources rapid and reliable (Fig. 26). The use of helium gas and mass-spectrometer leak detectors has greatly increased the sensitivity of many gaseous leak tests. With halogen compounds, as in refrigerator systems, leaks may be detected most sensitively with the positive ion detector.

Liquid-Penetrant Tests:

Liquid-penetrant inspection of the surfaces of test objects depends for its operation upon the mass transport of the penetrating liquid into the defects and discontinuities open to the surface. The penetrating liquids are initially applied to the objects by dipping, rinsing, spraying, or brushing. The liquids are left on the surface of the object for a period of time sufficient for them to penetrate all surface defects to which a passageway exists. The remaining penetrant is then cleaned from the exposed surface of the object, and the object is usually dried. It then is allowed to stand until that penetrant trapped within the defects and surface discontinuities has a chance to leak out. The indications produced by surface wetting near these defects are developed by various means to expose them clearly to the inspector.

The *oil-and-whiting* inspection method is the oldest of the penetrant methods in common industrial use. The addition of visible dyes has increased the visibility of its indications. The method is highly sensitive when applied carefully by skilled operators. The materials for *dye-penetrant inspection* are now commercially available in sealed spray cans. Four basic materials are supplied, as follows:

1. A liquid solvent, used as a precleaner, where grease or other dirt obscures the surface.

2. A red liquid penetrant to be sprayed, brushed, or dipped onto the surface, at a temperature over 60 F. Because of its high penetrating power, the liquid is drawn or dissolves its way into even fine defects. It is allowed to remain on the surface of the test object long enough to enter the finest cracks expected.

3. A water-miscible liquid-remover solvent which aids the wiping action in removing surface penetrant. For rough sand-cast or welded parts, the cleaner of step 1 may be used to facilitate wiping the surface clean.

4. A developer consisting of a volatile liquid suspension which dried to form a light powdery coating.

The developer serves three functions:

(*a*) It draws the penetrant out of defects onto the cleaned surface of the part by solvent and blotting action.

(*b*) It masks out slight traces of surface

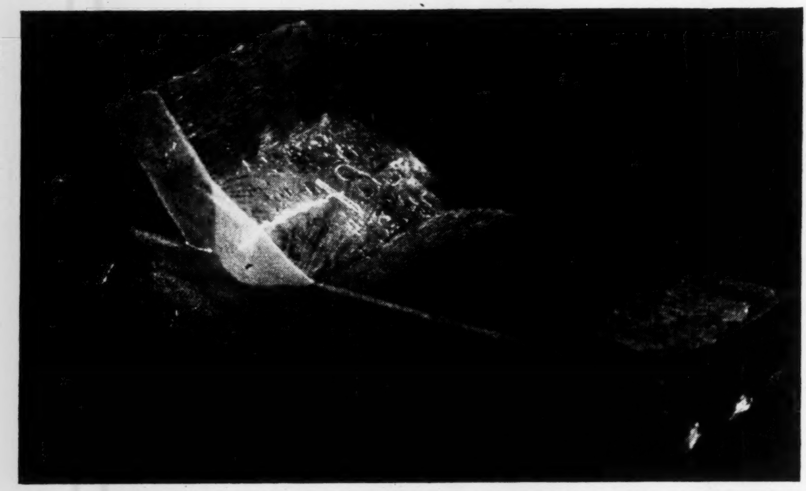


FIG. 26.—Zyglo Fluorescent-Penetrant Indication of Crack in Stainless Steel Weld Bead, Illuminated with Ultraviolet "Black" Light. (Courtesy Magnaflux Corp., Chicago, Ill.)

penetrant that may not have been removed completely.

(*c*) It serves to provide high color contrast between its white background and the bright red defect indications.

The dye-penetrant inspection method may be applied to locate defects open to the surface on many different materials, such as aluminum, magnesium, brass, cast iron, steel, stainless steel, carbides, stellite, plastics, and so on. It is suitable for indicating surface cracks (such as shrinkage cracks, grinding and heat-treatment cracks, fatigue cracks, and forging bursts), defects (such as seams and laps, cold shuts, and lack of bond between joined metals), surface porosity (such as shrinkage porosity or gas porosity in machined castings), and through leaks (in welds and other portions of container walls). The dye penetrants provide an easy through-leak test for walls up to about ¼ in. thick. The penetrant is sprayed on one side of the wall and allowed to be drawn through the leaks by capillary force. No pressure is required. After the penetrant has soaked through, the opposite face of the wall is inspected by applying the developer. Leaks show as bright red spots on the inspected side. The normal penetration rate in leak testing is very rapid. Coarse porosity in the leakage path provides little capillary force and slows penetration. Prior water or moist-air tests must be avoided, since trapped moisture in the leaks plugs fine passages, stopping the penetrant.

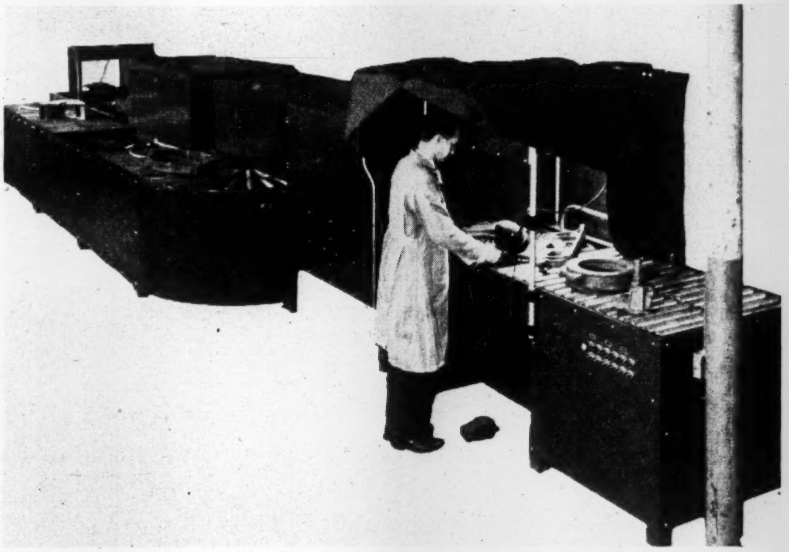
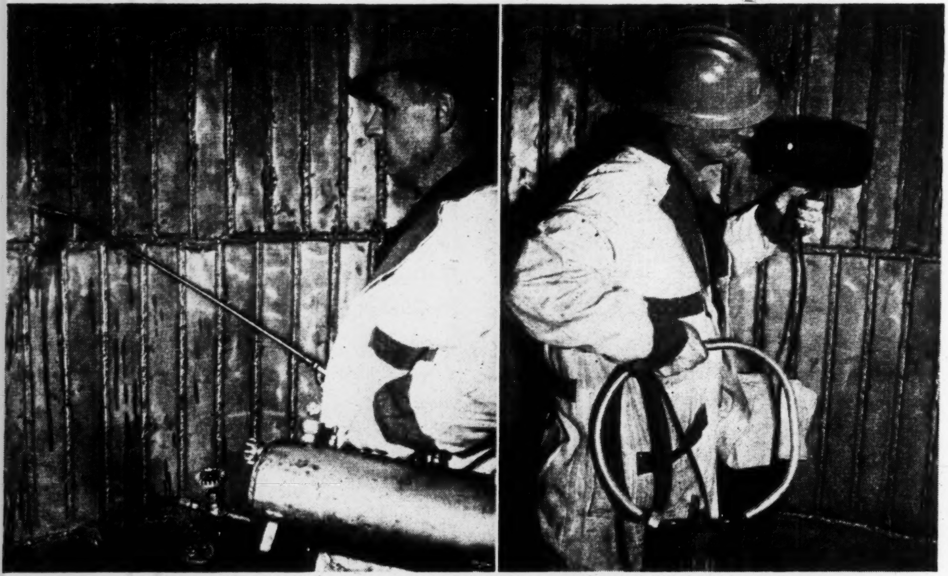


FIG. 27.—Automatic Conveyerized Zyglo Processing Unit for Fluorescent-Penetrant Inspection f Castings. (Courtesy Magnaflux Corp., Chicago, Ill.)

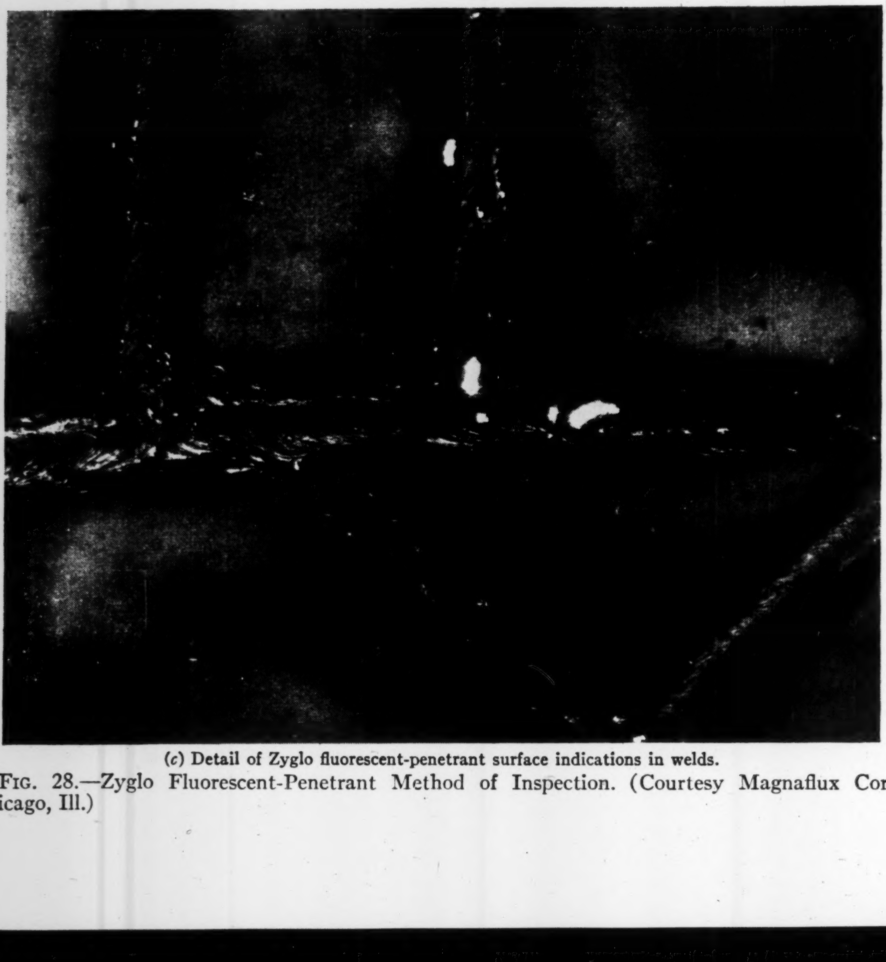
By far the most popular and widely used of liquid-penetrant inspection methods in industry is the fluorescent liquid-penetrant ("Zyglo") method. Its brilliant fluorescent indications of defects stand out under ultraviolet light with contrast not attainable with dye colors in ordinary white-light illumination (Fig. 26). In consequence, even minute defects are extremely clear and prominently visible. These high-contrast indications speed up inspection and increase the reliability of inspection, since it would be difficult to fail to see the fluorescent indications.

Completely mechanized equipment



(*a*) Spray application of Zyglo fluorescent penetrant to welded liner in storage tank.

(*b*) "Black light" examination of Zyglo indications in welded structure.



(*c*) Detail of Zyglo fluorescent-penetrant surface indications in welds.

FIG. 28.—Zyglo Fluorescent-Penetrant Method of Inspection. (Courtesy Magnaflux Corp., Chicago, Ill.)

exists (Fig. 27) for carrying out the basic steps in fluorescent-penetrant inspection. The penetrant is usually applied simply by dipping the parts (in a suitable basket) into the liquid penetrant. Larger parts may be handled by brushing or spraying (Fig. 28 (*a*)).

Since the fluorescent penetrant is water-washable, rinsing is done simply, either manually or automatically, by spraying water over the parts in a rinse tank. The use of water makes this step much less critical than the solvent cleaning used in most dye-penetrant methods, since the water does not tend to remove the penetrant from the true defects. Parts are next dried by hot-air oven or blower, or manually by wiping. Developing may be carried out either by wet or dry methods. In the *wet method*, the parts are dipped into a colloidal water suspension of a special developer, and then placed in a drier. A uniform layer is deposited on the surface of the part. This results in increased brilliance and contrast in the fluorescent indication. In the *dry method*, parts are dusted with a dry developing powder while placed in a tank containing the powder. The powder helps draw the penetrant out of the flaws by capillary action, resulting in brilliant indications on a suitable background.

The inspector's observation of the parts is carried out in a darkened booth equipped with ultraviolet lamps. These illuminate the test object with "black light" of 3650 Ångström units wavelength. The penetrant indications fluoresce brilliantly under this illumination, with a characteristic green color near the eye's maximum response frequency. The manner in which these indications "flash up" is one of the most dramatic forms of indication in the entire nondestructive testing field.

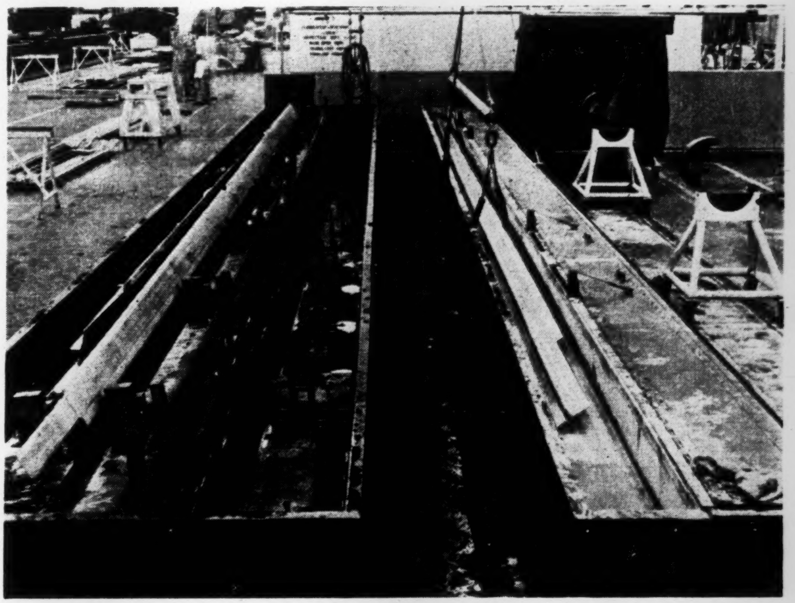


FIG. 29.—Zyglo Fluorescent Liquid-Penetrant Inspection of Aircraft Spar Caps. (Courtesy Douglas Aircraft Corp., Photo Laboratory, Santa Monica, Calif., and Magnaflux Corp., Chicago, Ill.)

The fluorescent-penetrant method of inspection can also be readily applied to large structures in the field. Figure 28 shows successively the spray application of Zyglo penetrant, the inspector's examination with "black light," and typical weld-defect indications found on a welded storage tank structure. The increasing size and critical loading of aircraft structures has led to careful fluorescent-penetrant inspection of primary structural elements such as wing spars, for which long inspection units have been especially designed (Fig. 29). The method is now widely used throughout industry for inspection of nonferromagnetic materials such as the light alloys, stainless steels, and ferromagnetic materials which it is undesirable to magnetize.

Filtered-Particle Tests:

Filtered-particle tests employ selective mass transport to locate cracks open to the surface in porous materials. The probing medium is a liquid dispersion of particles, often coated with fluorescent pigments. When applied to a porous body, such as an unfired ceramic, the liquid carrier is absorbed into the body through accessible surfaces. Where discontinuities, such as cracks, connect with the exposed surfaces, they absorb liquid along their interfaces to so great an extent that the suspended particles are drawn to the site of the defect. Here, being larger than the defect opening, they filter out to produce striking indications (Fig. 30).

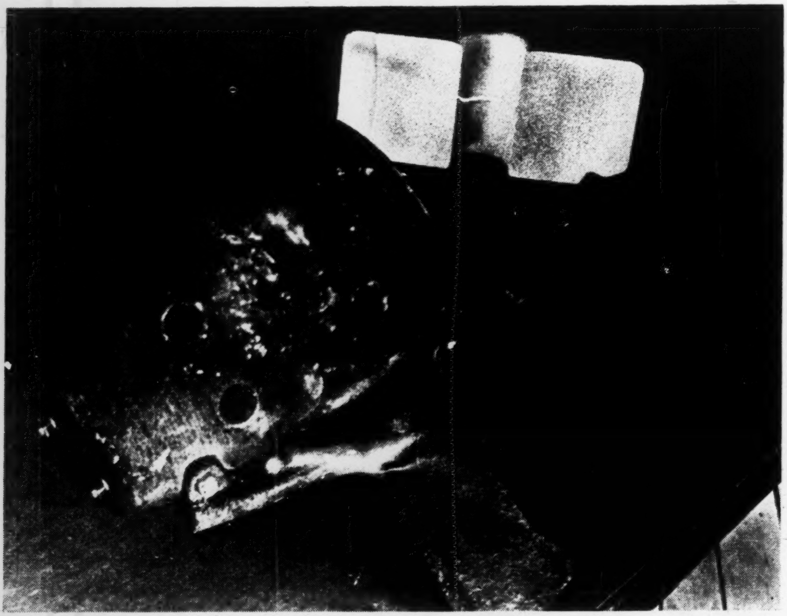


FIG. 30.—Partek Filtered Fluorescent Particle Indication of a Crack in a Sample of Unfired Clay. (Courtesy Magnaflux Corp., Chicago, Ill.)

Commercially available inspection fluids consist of a light petroleum distillate carrying in suspension a wide range of particle sizes in the micronic range. They may be applied to test objects by spraying, by dipping, or with simple devices such as an eye-dropper or oil squirt gun. With fluorescent-coated particles, a "black light" source of ultraviolet illumination is used.

The filtered-particle ("Partek") inspection method has found extensive application in the examination of green (unfired) ceramics, such as clay ware, porcelain insulators, and pottery. Experience indicates that cracks shown by this method in green ware always result in cracks in the fired ware. Rejection prior to firing reduces the costs which would be involved in handling and firing pieces which would be rejected ultimately. The nature of both liquid and particles is such that they "fire off" at low temperatures, without damage to the finished ware.

Brittle-Coating Tests:

Brittle-coating ("Stress-Coat") tests also depend primarily upon mass transport as a medium for probing the test object. In this method, the surface of the test object is cleaned, and a brittle lacquer is applied and allowed to dry and harden under controlled environmental conditions. When hard, these coatings are so brittle that they elongate very little before cracking, the cracks generally being transverse to the direction of strain. If the brittle-lacquer-coated test object is now subjected to mechanical stress (such as in proof loading) which strains it, the coatings cannot elongate as much as the base material of the test object. Where stress concentrations exist, the brittle coating cracks in a distinctive pattern as the base material is strained. The range of strains at which the brittle coatings can be made to just start cracking is 0.0005 to 0.003 in. per in. under normal operating conditions. The coatings can be further sensitized down to 0.0001 in. per in. strain by cooling them while the static load is applied. They respond equally well to dynamic loads and show by increasing patterns of cracking the increase of strain as loads are gradually applied.

A variety of brittle-coating materials is available, for use in different temperature or humidity environmental conditions, as well as for different stress levels required to fracture the coating. In practice, the test objects are cleaned and an aluminum-pigmented undercoating is sprayed on the surface, to provide a uniform bright working background for the brittle coatings. The brittle-coating material is then sprayed on and allowed to dry overnight at room temperature or slightly above. More rapid drying can be attained at 130 F. Calibration strips are coated simultaneously and dried under the same conditions as the part under test. These may be evaluated by applying known strains. Quantitative accuracy is possible only at those strain levels at which cracks start to form.

The test object is subjected to the desired stress loading, and the incidence and patterns of cracks in the brittle coatings observed carefully. This establishes stress magnitudes (at start of cracking) and stress distribution or concentrations (by the pattern of cracks). Suitable dyes are available to stain the cracks for easier observation and recording. The brittle-lacquer technique has found wide application in experimental design and stress analysis, in measuring assembly stresses and residual stresses resulting from fabrication, in measuring strain due to impact and other dynamic loads, as an adjunct to proof tests, and in measuring stresses applied in service. In these applications, it can predict the locations of stress concentration and the probable locations of failures due to such stresses. It has also found use in establishing the nature of service conditions which produced unexpected service failures, to guide redesign or reinforcement of the test objects.

NONDESTRUCTIVE TEST METHODS BASED UPON RELATED PHENOMENA INVOLVING BOTH TRANSPORT OF MATTER AND CORRESPONDING TRANSFER OF ENERGY

In some phenomena, the transport of matter is dependent upon a corresponding transfer of significant quantities of energy intimately linked with and essential to the transport of matter. For example, the motion of high-energy charged particles, such as electrons, transfers energy which may be released if the particle is stopped suddenly (as electrons are stopped when they strike the target of an X-ray tube). In the same sense, the transfer of energy often requires motion of matter, as in heat transfer, ultrasonic mechanical vibrations, or triboelectric phenomena. Many powerful nondestructive test methods depend upon these more complex media for probing the test object (Table VII).

TABLE VII.—TYPICAL NONDESTRUCTIVE TEST METHODS BASED UPON RELATED PHENOMENA OF TRANSPORT OF MATTER AND CORRESPONDING TRANSFER OF ENERGY.

Test Method	Form of Matter Transported	Form of Energy Transferred	Mechanism of Detection of Material Properties and Discontinuities	Forms of External Test Indications
Neutral particle beam tests	Neutrons, atoms, molecules, etc.	Gamma rays, kinetic energy, chemical, atomic, molecular energy, etc.	Absorption, scattering, deflection, attenuation of particles, etc.	Gamma ray image on films, ionization gage indications, crystal or Geiger counter indications, etc.
Charged particle beam tests	Electrons, alpha particles, ions, etc.	Electric field energy, kinetic energy, etc.	Absorption, deflection, scattering, etc.	Geiger or crystal counter indications, ionization gage indications, images on films, etc.
Electric current conduction tests	Electrons (in metallic conductors), electrons and "holes" in semiconductors, electrons and ions in liquids and gases, etc.	Electric field energy, magnetic field energy, heat, etc.	Distortion of current distributions, heat, magnetic fields of currents etc.	Resistance indications, potential drops, magnetic fields, heating, ohmic losses, etc.
Electromagnetic induction tests	Electrons, ions, magnetic domains, dielectric polarization, etc.	Electromagnetic field	Interruption or distortion of eddy current paths, magnetic field distortion, hysteresis loss, resistance loss, etc.	Amplitude of primary (source) or secondary (probe) oscillations, total losses, circuit resonance frequency, Q measurements, induced magnetic field strength, etc.
Sonic and ultrasonic mechanical vibration tests	Solid, liquid, or gaseous matter. Compressional, shear, or surface waves in solids, etc.	Mechanical vibrations	Reflection, refraction, scattering, transmission, transit time, phase shifts of sound waves, etc.	Waves or vibrations (displacements of matter) at exposed surfaces of test objects, piezoelectric or magnetostrictive probe signals, powder patterns, Pohlman patterns, cavitation, etc.
Thermal conduction tests	Solid, liquid or gaseous matter in random oscillations of impacts	Heat	Distortion of temperature distributions	Temperature, distribution at exposed surfaces, electrical resistivity, Curie point, chemical changes, solvent evaporation, thermocouple signals, etc.
Triboelectric and thermoelectric tests	Electrons	Electric field energy	Potentials arising at contacts or upon separation of contacts, etc.	Electric potentials or currents in electric circuits or electrometers, etc.
Chemical and electrochemical tests	Atoms, ions, etc.	Chemical binding energy, heat, etc.	Products of chemical reactions	Visible markings or deposits, images on electrographic paper, etc.

The range of application of these phenomena depends greatly upon limitations both of transport of matter and of transfer of energy. For example, beams of charged high-energy particles, such as electrons and alpha particles, are rapidly attenuated when they pass through dense, solid materials. Consequently, tests using these particles as probing media are usually suitable only for examination of thin sheets or surface layers of thick materials, as in electron diffraction or in the electron microscope. Neutrons, on the other hand, have significantly greater ranges in some solid materials, but react with hydrogen-bearing materials so as to produce gamma rays and are attentuated accordingly. Ultrasonic vibrations of metallic materials with low damping losses may penetrate great distances; such waves have been reported to have penetrated up to 50 ft of steel or concrete with adequate strength of transmitted or reflected signal to be useful in nondestructive testing.

Neutron and Other Uncharged-Particle Beam Tests:

Test methods in which neutrons, atoms, and other uncharged particles moving at high velocities in beams are used to probe the test objects fall into this class. To date, such test methods have found few applications because of the relative difficulties of producing and controlling beams of such neutral particles and of detecting their intensities after modification by test objects.

Neutron beams have been produced by means of radioactive sources whose gamma emanations pass through beryllium to create the neutron flux. Such sources have found applications in atomic energy research and in neutron logging of oil wells. In the latter application, the neutrons react with hydrogen-bearing fluids in earth formations, producing secondary gamma rays which give the logging signal.

A neutron image converter has been proposed, in which a neutron beam transmitted through the material of a test object would be recorded by means of an image tube, somewhat similar to those used to reproduce X-ray images. With narrow neutron beams, the detector might consist of a suitable gamma-radiation detector in a hydrocarbon enclosure. In addition to direct neutron gaging of material thicknesses, it has also been proposed that a neutron beam might be employed to detect the presence of a hydrocarbon within a metallic enclosure, as with petroleum products in steel pipes or tanks, or rosin cores in solder. To date, however, no practical nondestructive tests based upon neutral particle beam inspection have been commercially developed for wide use in industry.

Electron and Other Charged-Particle Beam Tests:

Several valuable test methods based upon the use of beams of electrons or other charged particles have found important industrial applications in nondestructive testing. In these tests, the charged particles impinge upon the test objects, being diffracted, or transmitted with attenuation, to produce images suitable for detection and interpretation. Diffraction of electrons and other charged particles has proved useful for surface inspection and identification of materials. Transmission of electron beams through thin layers of test materials provides remarkably detailed information concerning their structures.

The beams of electrons may be produced with an electron gun, such as is commonly used in cathode ray and X-ray tubes. Or they may be produced by the irradiation of materials with gamma rays or other high-energy photons or particles, as is well known in the use of lead screens to intensify X-ray images in film radiography. Other means of producing beams of high-energy charged particles have been developed in mass spectroscopy and induction accelerator applications.

The production of images by passing electron beams through test materials has found many valuable applications. In the electron microscope, such particle beams transmitted through thin replicas of material surfaces are focused magnetically to produce greatly enlarged electron radiographs upon films or fluorescent screens. In electron radiography, the electron flux produced by irradiation of an intermediate material (such as lead) with X-rays or gamma rays is passed through a test object in intimate contact with both the electron source and the recording film, to produce useful electron radiographs. Similar autoradiographs are produced with electrons (beta particles) emitted from radioactive isotope sources to reveal structure or distribution of radioactive constituents in the test object.

In electron-diffraction techniques, a beam of electrons is directed at a glancing angle of incidence upon the test object to produce diffraction patterns characteristic of thin surface films of contaminants or of the test object itself. In the mass spectroscope, charged particles (atoms, molecules, etc.) are magnetically separated in terms of mass and charge, to produce characteristic patterns for identification purposes or for sorting or separation. Cathodic etching takes advantage of the selective etching of electrons impinging upon test objects in vacuum chambers to reveal structure for metallographical purposes.

Electrons and alpha particle beams have found practical industrial applications in "nucleonic" gaging of sheet thicknesses of thin metallic foils, paper, and plastic materials. In these gages (Fig. 31), radioactive sources of beta rays or other probing beams of charged particles are placed on one side of the sheet material to be gaged, and suitable detectors, such as Geiger counters, are placed on the opposite side, to detect the transmitted-particle beam intensities.

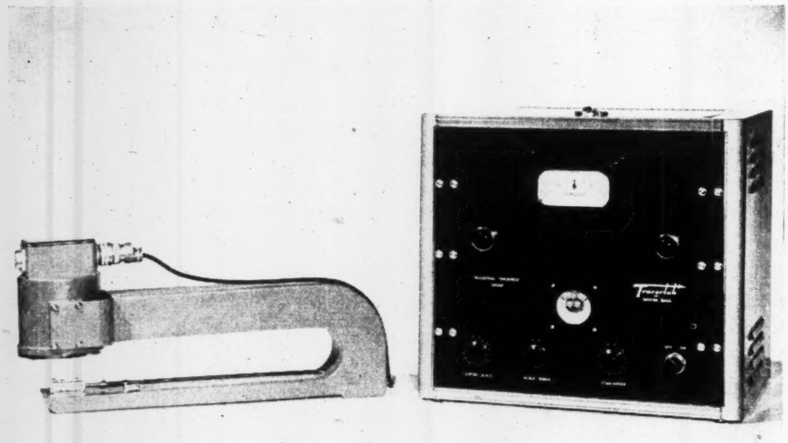


FIG. 31.—Tracerlab Beta-Ray Sheet-Thickness Gage. (Isotope source at bottom of yoke; detector in housing at top of yoke.) (Courtesy Tracerlab, Inc., Boston, Mass.)

Electric Current Conduction Tests:

Tests based on electric current conduction are characterized by a flow of heavy electric current from an external source through the test object by means of direct contacts or electrical connections. (Tests in which electric currents are induced in the test object by varying electromagnetic fields are discussed in the next section of this paper.) Clean, scale-free bare metal surfaces and contacts under considerable pressure are usually required to avoid contact overheating or burning of the test object. The current flow in the test object produces differences in electric potential, magnetic fields, and heat or temperature gradients which may be influenced by defects or variations in the material.

The flow of electric currents in conducting materials is a matter of mass transport of charged particles. (These consist of electrons in metallic conductors, positive or negative charges or "holes" in semiconductors, and ions in liquids or gases.) Because of electric field conditions, however, this transport of charged particles of matter often transmits considerable energy. It may often be readily detected by the changes in the electromagnetic field which accompany the changes in position of the electric charges.

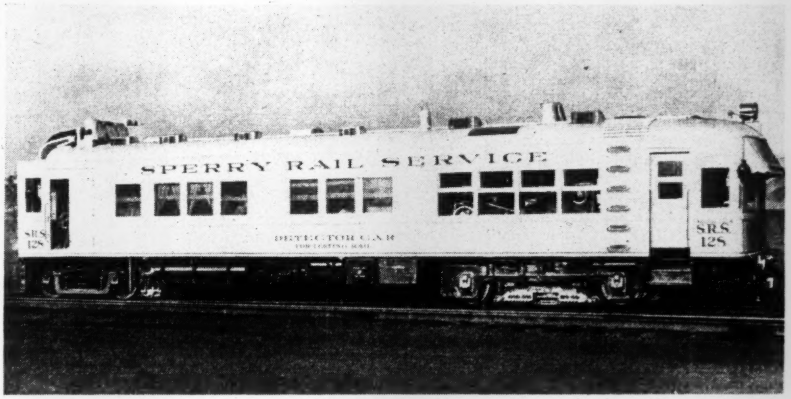


Fig. 32.—Sperry Rail Detector Car. (Courtesy Sperry Rail Service, Sperry Products Corp., Danbury Conn.)

At low frequencies, *the flow of electric charges* may be readily detected by the static magnetic fields they produce. In the case of a conducting material containing a discontinuity, the interruption or deformation of the flow of current produces a corresponding deformation in the static magnetic field, which might be detectable outside the test object. When electric currents flow through *ferromagnetic* materials, they induce magnetic fields which may be far more sensitive to discontinuities in permeability than were the electric currents themselves. Here, the *magnetic field* now becomes the primary means of sensing material properties and discontinuities and of relaying the desired information to detection points outside the test objects.

The electric current used as the probing medium in these nondestructive tests is usually supplied from an external battery, welding generator, or other source of low-voltage, high-current electric power. The reaction of the test object upon the probing current is detected by means of potential-drop measurements, thermal effects, or (generally most successfully) by pickup coil measurements of the magnetic field produced at the surface of the test object as a consequence of the flow of electric currents and their interruption or deformation by discontuinities. Obviously, electric current conduction tests are usually limited to conducting materials, such as metallic parts, or to other materials with sufficient electrical conductivity to permit the flow of a detectable current.

The most outstanding industrial application of the electric current conduction type of test is in the electrical testing of steel rails. The Sperry rail car (Fig. 32) is designed to pass a heavy electric current through the rail and to explore the magnetic field produced by this current by means of induction pickup coils. This method replaces an earlier, less successful attempt to use potential-drop pickups. To date, such rail cars have inspected over two million miles of track, and more than one million defective rails (Fig. 33) have been detected and removed from service.

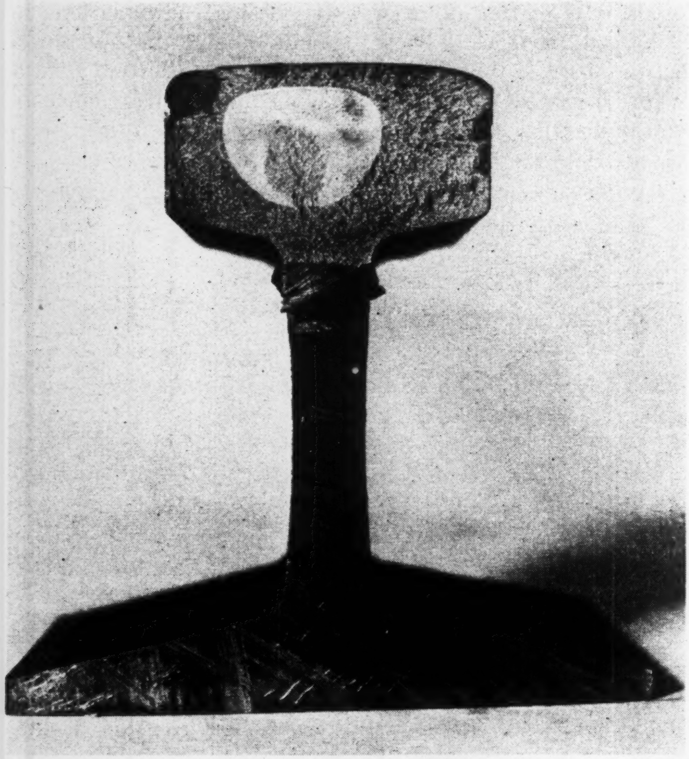


FIG. 33.—Transverse Fracture in Rail. (Courtesy Sperry Rail Service, Sperry Products Corp., Danbury, Conn.)

Special applications of electric current conduction tests include methods of measuring the wall thickness of plates, sheets, and tubes, from one side only. The probing electric current is introduced into the test object by means of a pair of current electrodes. The potential drop in the plate (an inverse function of its thickness) is measured by means of an independent set of potential electrodes. To avoid errors due to thermoelectric effects, or to ohmic potential drops at the potential electrodes, use is often made of potentiometer detection circuits which, when balanced, require no flow of electric current through the potential probes. Figure 34 shows a typical relation between material wall thickness and test indications.

Electromagnetic Induction Tests:

Electromagnetic induction tests are

characterized by the induction of varying electrical currents in the test object by means of repeated variations in an electromagnetic field. This method contrasts with the electric current conduction tests in which current flows into the test object through direct electrical contacts from an external source. No input contacts are required with induction-type tests. The induced current in the test object produces differences in electrical potential, magnetic fields, and heat or temperature gradients. When alternating or varying currents are induced in ferromagnetic materials, heat is produced not only by ohmic losses proportional to the square of the current density, but also by hysteresis losses in the magnetic material. The total "iron" losses, composed of both eddy current losses and hysteresis losses, are sometimes employed to indicate material properties. The pickup may detect variations in electrical potential distribution, in magnetic field strengths, in high-frequency electromagnetic wave properties, in temperature, in mechanical force or torque, or in losses in the material of the test object, or combinations of these factors. The complex nature of the probing medium in electromagnetic induction tests is apparent. Energy is transferred through the electromagnetic field. The flow of electrons in the test material also transfers energy and absorbs energy, as do the variations in the state of magnetization of the materials.

Dynamic electromagnetic fields provide an unusual combination of energy transfer through space, and related local movements of matter within test objects The electromagnetic field, like light or X-rays, may be transmitted through vacuum, in the complete absence of matter. It penetrates materials to varying degrees, depending upon their properties. And it induces local movements of matter within the materials, depending upon their nature. In electrically conducting materials, the electromagnetic field induces the movement of electrons or electric currents (such as the eddy currents in magnetic analysis). In magnetic materials, the dynamic electromagnetic field induces local oscillations of the elementary magnetic domains and, in some cases, magnetostrictive effects. In dielec-

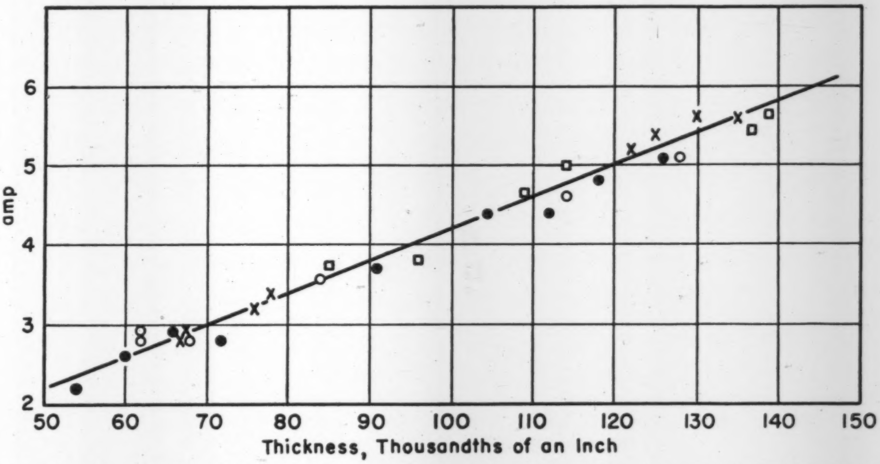
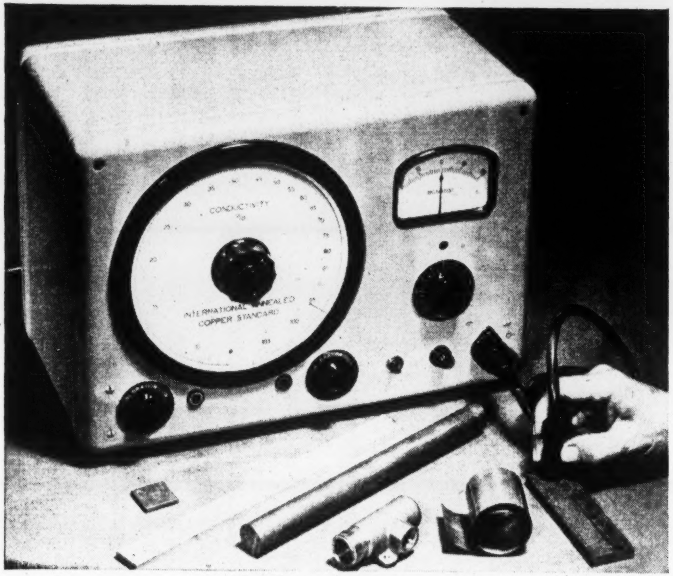


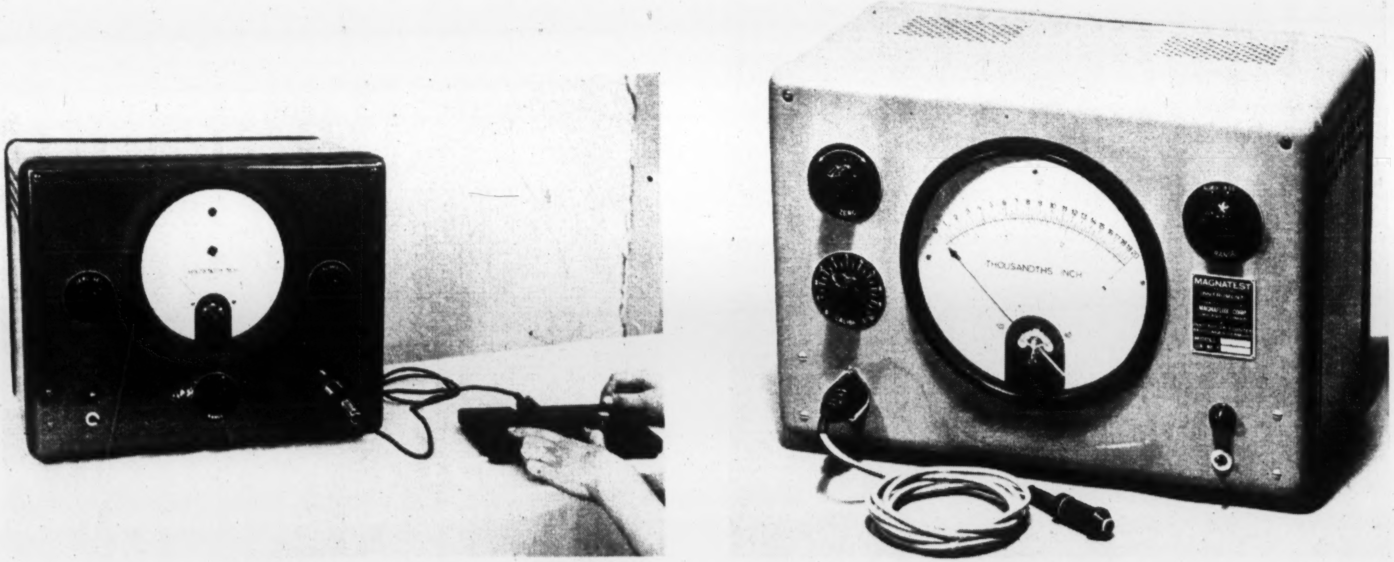
Fig. 34.—Correlation of Electric Current Conduction Test Indications with Wall Thickness of 4-in. OD Boiler Tubes. (Adapted from Thornton and Thornton, "The Measurement of the Thickness of Metal Walls from One Surface Only," *Proceedings*, Inst. Mechanical Engrs., Vol. 140, pp. 349–399.)


CONDUCTIVITY
%
INTERNATIONAL ANNEALED
COPPER STANDARD

(*a*) Conductivity tester.

MAGNATEST
INSTRUMENT
MAGNAFLUX CORP
SPREAD
PHASE SHIFT
SENS

(*b*) Multitester (for rods).


THOUSANDTHS INCH
MAGNATEST
MAGNAFLUX CORP

(*c*) Wall-thickness tester.

(*d*) Coating-thickness tester.

Fig. 35.—Typical Electromagnetic Induction Testing Instruments of Institut Dr Förster. (Courtesy Institut Dr. Förster, Reutlingen, Germany, and Magnaflux Corp., Chicago, Ill.)

tric materials, applied dynamic fields may induce similar oscillations in polarization of local regions, or piezoelectric (electrostrictive) effects. These movements of matter within the test object absorb energy from the applied electromagnetic field. This energy may be converted into heat by resistance, hysteresis, and dielectric losses. The extent of each possible reaction is influenced by material properties such as electrical resistivity, magnetic permeability and retentivity, dielectric susceptibility, and hysteresis. These properties, in turn, are complex functions of material properties such as composition, structure, stress, and many other variables. Thus, the reactions of the test object to the electromagnetic field often produce indications from many different internal causes, so that interpretation requires extensive experience and selective instrumentation. Electromagnetic induction provides a versatile probing medium with several possibilities of reaction with test objects and with good information transfer capabilities.

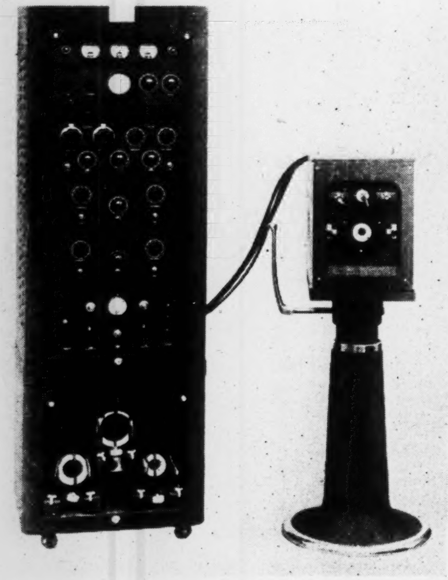


FIG. 36.—Magnetic-Analysis Equipment for Nondestructive Testing of Tubes and Bars. (Courtesy Magnetic Analysis Corp., Long Island City, N. Y.)

Very intensive research on electromagnetic induction methods of nondestructive testing in Germany during the past twenty years has resulted in a particularly effective and successful line of electromagnetic induction testing instruments (Fig. 35). Various electromagnetic induction instruments provide simple production testers for locating cracks, sorting by composition and heat treatment, thickness testing, and other tests, for both ferrous and non-ferrous materials, parts, tubes, bars, wires, and special applications. These have been adopted in German industry for many uses, including evaluation of light-metal-alloy materials.

Magnetic-analysis equipment (Fig. 36) provides a unique combination of several sensitive magnetic measurements, each analyzed and evaluated separately by electronic discriminating circuits. The magnetizing coils are supplied with 60-cycle alternating current carefully isolated from line fluctuations by voltage and current regulators. The sinusoidal magnetizing coils induce varying magnetic conditions in different metallic materials placed in the test unit. These magnetic variations induce changes in phase and amplitude of fundamental frequency, as well as wave form distortions, in the emf signals induced in the detector coils. The changes in phase and amplitude of fundamental frequency are determined with circuits which include balancing, filtering, amplifying, and indicating electronic networks for the small a-c voltages. To select the optimum points in the distorted wave forms for analysis, special "point inspection" gating circuits are used. These select any desired short interval, of only 50 microseconds duration, or one electrical degree, out of each cycle of 360 electrical degrees. Selecting these points permits elimination of many magnetic variables of no significance from the inspection. Each specimen is subjected to two such "electronic point inspections," to sort materials by grade, structure, hardness, and processing conditions.

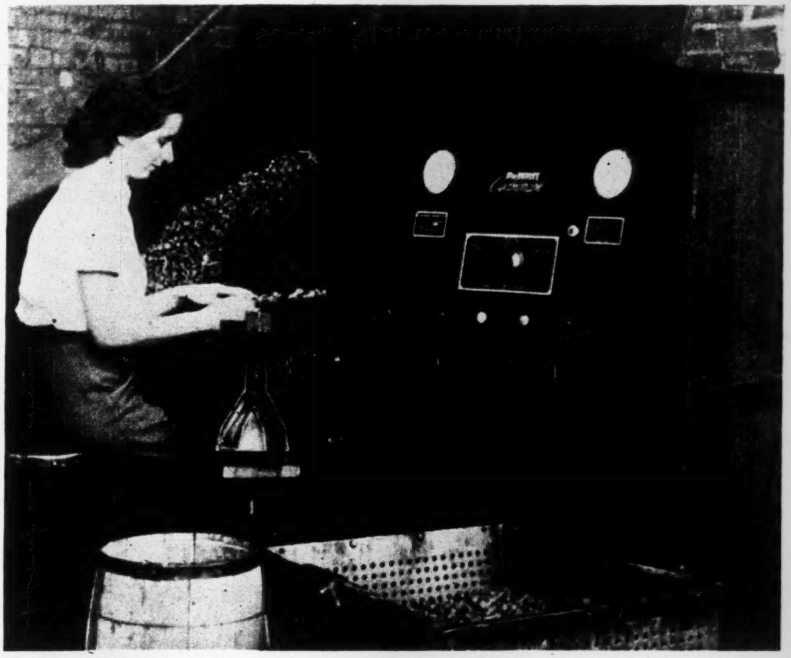
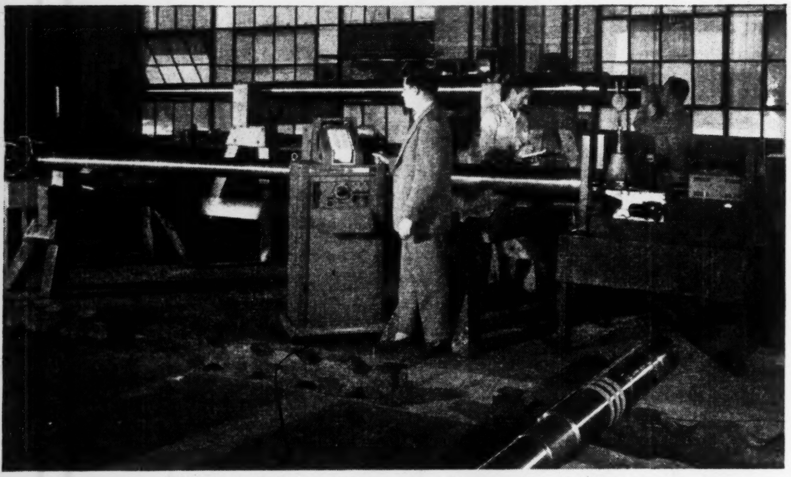


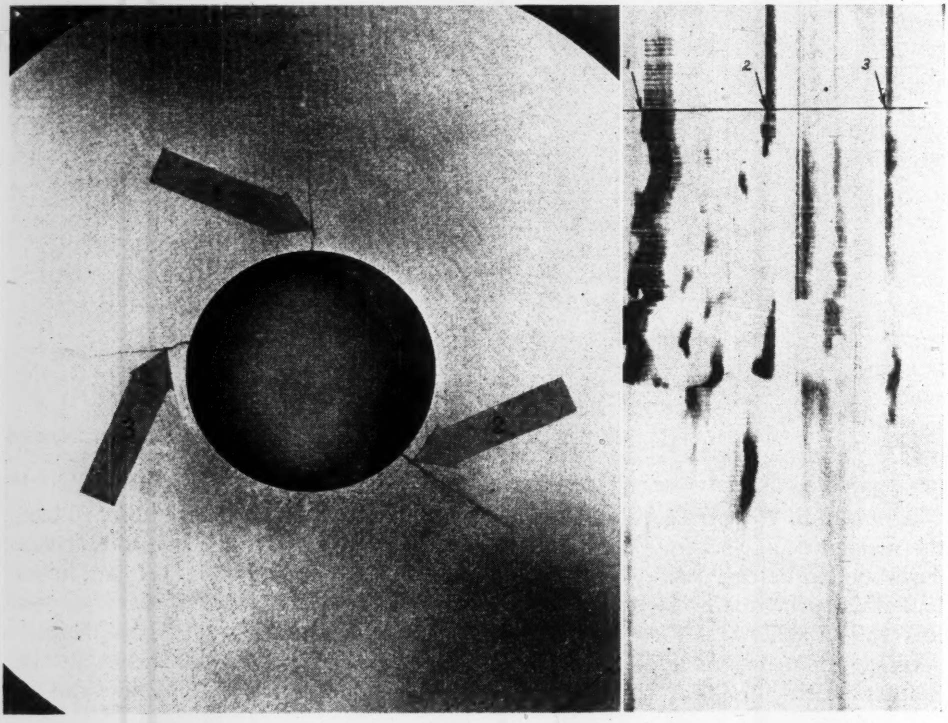
FIG. 37.—Rapid Electromagnetic Induction Sorting of Production Parts with Original Dumont Cyclograph (Model 244). (Courtesy J. W. Dice Co., Englewood, N. J.)

In addition to sorting the materials, the magnetic-analysis equipment detects flaws such as cracks, seams, laps, slivers, and other surface defects with depths not less than 0.001 in. for each $\frac{1}{16}$ in. of specimen diameter. In addition, internal defects such as cupping and pipe in smaller diameter material are located. These defects are located by the differential pickup coil method. Two adjacent portions of the specimen are scanned by pickup coils connected in series opposition. In this way, the average properties of the material cancel out, and only local variations are detected. These differential signals are also analyzed electronically to indicate significant flaws in the materials tested.

Magnetic-analysis inspection is presently used in the cold-drawn steel industry for production testing of hot-rolled, cold-drawn, heat-treated, stress-relieved and annealed machine-straightened bars, tubes, and wires of all shapes and sizes up to $5\frac{1}{2}$ in. in diameter. Seamless tubing is inspected for outside diameter and inside diameter flaws and to identify grade and structure. Butt-welded tubing is tested for open and weak welds, as well as for inclusions and burned sections. Small parts are usually inspected with comparators only for structure and analysis, but normally not for defects. During the past twenty years, the method has developed into a valuable tonnage pro-



(*a*) Installation at Borescope Inspection Station.



(*b*) Section of cracked gun tube.

(*c*) Facsimile recording of cracks (shown in (*b*)) from Magnetic Borescope.

FIG. 38.—Watertown Arsenal Laboratory Magnetic Recording Borescope Used in Gun-Tube Inspection. (Courtesy Carleton E. Hastings, Watertown Arsenal Laboratory, Watertown, Mass.)

duction test method which is used daily in a number of major steel mills.

The Cyclograph (Fig. 37) provides a wide-frequency-range oscillator in which the test coil is part of the tuning circuit. Regenerative feed-back control allows adjustment of the initial energy output of the oscillator to any desired level. The test frequency is selected by choosing the test coil and by adjusting capacitors in the control unit. Core losses occurring in the metal specimens inserted into the field of the test coil decrease the output of the oscillator. This output of the oscillator is viewed on a cathode-ray tube screen, whose pattern can be correlated with the metallurgical characteristics of the test pieces. At low frequencies (of 2 to 10 kc), these core losses are mainly governed by the magnetic properties of the material of the test object, if it is of iron or steel (ferromagnetic). At higher frequencies, the core losses consist mainly of eddy current losses. These higher frequencies are generally used for inspection of uniformity or analysis of non-ferrous metals. At very high frequencies, the electromagnetic field of the test coil is confined to the surface layers of the test object, due to skin effect. These frequencies are used for tests such as case depth of carburized parts, decarburization, plating thickness, and surface stresses. Cyclograph indications have been correlated with applied and residual stresses, with fatigue damage, as well as with material analysis, structure, hardness, brittleness (stress gradients), degree of cold working, and various sorting applications. The Cyclograph, in measuring these magnetic losses, is not designed to be sensitive to defects or local discontinuities and does not detect them.

The Ferrograph provides a magnetic-analysis method in which the response of a ferromagnetic sample to a *low*-frequency (23 cps) alternating magnetization, and to its third harmonic (69 cps) are compared with each other. In the Ferrograph, the relative amplitudes and phase angles between the fundamental and third harmonic signals are displayed on the fluorescent screen of a cathode-ray oscilloscope (similar to a television viewing tube). The instrument can correlate carbon content in samples of similar chemical analysis. It can also distinguish between high- and low-alloy content samples and separate high- and low-alloy samples with the same carbon content.

A particularly outstanding recent application is a method for recording defects on the interior surface of gun barrels, which produces facsimile records of the entire surface and the location of the defects, such as seams, laps, and cracks (Fig. 38). This method is now being subjected to development into a production testing device.

Electromagnetic induction principles have been applied in an inspection device for nonmagnetic tubes. The device includes an electromagnetic induction probe which is pushed or pulled through tubes by a cable. As the probe moves through the tube, a strip recorder charts or indicates the position of defects. Since the probe can be passed through tubes without removing them from the equipment in which they are installed, it permits quick inspection. The device has been particularly applied to inspection of tubes in heat exchangers, condensers, and similar tubular equipment. It is reported to detect dezincification, eroded and corroded pits, cracks, strained areas, changes in alloy or chemical composition, and abnormal changes in physical dimensions.

Ultrasonic and Other Mechanical Vibration Tests:

Mechanical vibration tests are characterized by the establishing of mechanical vibrations in the test object, and their detection by suitable means. The vibrations may be natural frequency vibrations (as when the test object is excited by a hammer blow) or forced sonic or ultrasonic vibrations. At the higher frequencies, the vibrations tend to travel in beams, which may be transmitted, scattered, or reflected locally by discontinuities.

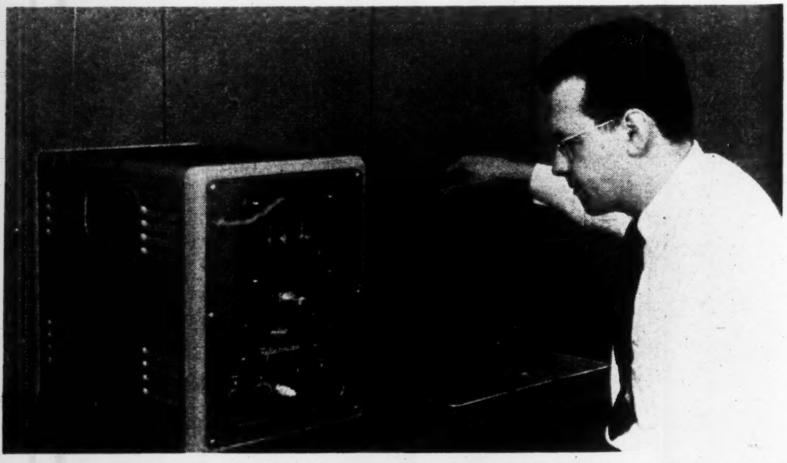


FIG. 39.—Sperry Ultrasonic Reflectoscope Used to Show Indications of Internal Defects in Portion of Railway Car Axle. (Courtesy Sperry Products, Inc., Danbury, Conn.)

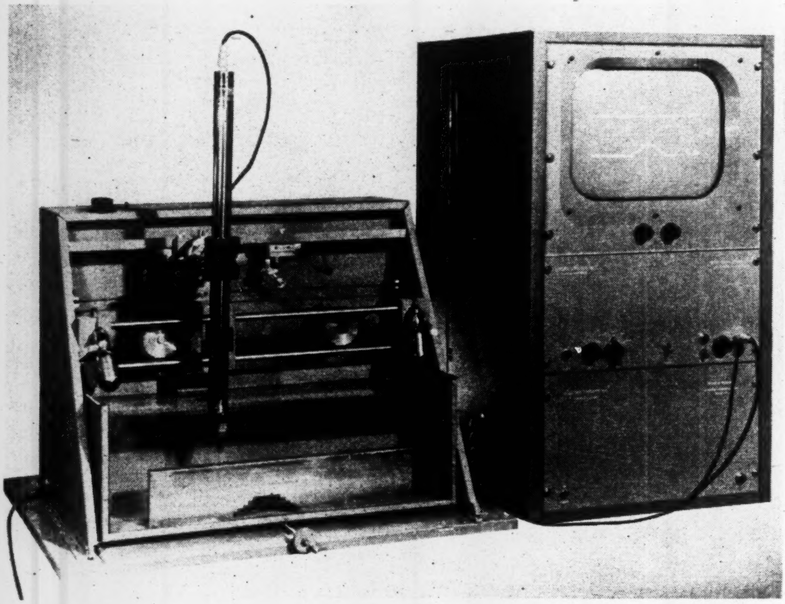


FIG. 40.—Electrocircuits, Inc., Ultrasonic Immersion Scanning Inspection Unit Reproducing B-scan presentation of discontinuities in aluminum alloy test block. (Courtesy Electrocircuits, Inc. Pasedena, Calif.)

The vibrations are usually established in the test objects by means of transducers operating from electronic power supplies. For lower frequency applications, the transducers may be electrodynamic (as in radio loud speakers) or magnetostrictive types. For higher frequencies (in the range of megacycles), quartz crystal transducers are most widely used. Most such transducers have only a limited frequency range through which they operate efficiently. Fluids, such as oil or water, are usually needed in order to couple the transducers to the test objects so as to transfer the vibratory energy efficiently.

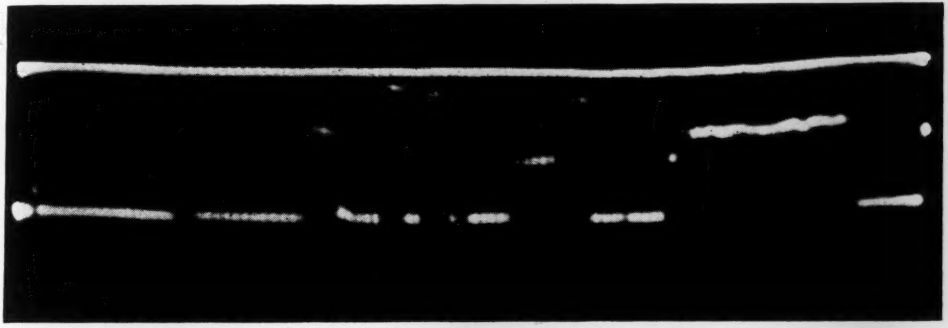


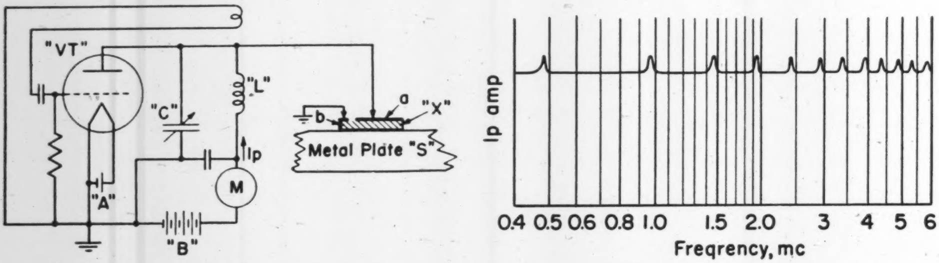
FIG. 41.—"B-Scan" Television-Type Presentation of Surfaces and Laminations in $\frac{5}{8}$-in. Aluminum Plate Detected with Immersion Ultrasonic Scanner. (Courtesy Electrocircuits, Inc., Pasadena Calif.)

The transmitted or reflected ultrasonic beams are usually detected by means of similar quartz crystal transducers (in many cases the same transducer as was used to establish the vibrations). With immersion techniques, limited success has been obtained by the use of a cell containing small particles in a liquid suspension, to present an image of the ultrasonic beam. At low frequencies, the vibrations may be readily detected with microphonic devices or crystal cartridges such as are used in phonograph reproduction. The use of small particles, such as sand, sprinkled onto the test object, has proved useful in establishing the modes of natural vibration at sonic frequencies.

Pulse-reflection techniques, such as are used in sonar detection of submarines, have been developed to a high degree for inspection of metallic materials for discontinuities. The ultrasonic reflectoscope uses a quartz crystal to introduce short (5 microsecond) pulses of ultrasonic frequency (0.5 to 5 mc) vibrations as a probing medium into the test object (Fig. 39). These high-frequency pulses travel great distances (up to 50 ft) in steel and some other metallic materials; however, large grain size introduces scatter and attenuation of such beams. The pulses are reflected from discontinuities, such as voids or cracks, and return to the transmitting (or receiver) quartz crystal transducers as echoes. The time from initial pulse to their return measures the distance of the discontinuity from the transducer, so that when the pulses are displayed upon a cathode-ray oscilloscope, the discontinuities can be readily located.

More recently, the pulse-reflection technique has been extended to higher frequencies and immersion techniques, which permit automatic scanning of the test object with the transducer (Fig. 40). The information obtained from the ultrasonic probe is displayed upon a "B-scan" cathode-ray picture tube (Fig. 41), so as to present a cross-section of the entire test object and a graphic picture of the discontinuities within it. Three dimensional probing, with electronic computation, has also been developed experimentally, with equipment based upon these principles.

Ultrasonic resonance has also been applied to thickness gaging with similar quartz crystal probes (Fig. 6). The oscillator which energizes the transducer is continuously tuned throughout a range of frequencies, including those at which resonance occurs (Fig. 42). At each resonant frequency, the mechanical impedance or amplitude conditions are reflected into the electronic circuit and produce "pips" or detectable deflections on the screen of a cathode-ray tube. An alternative form of equipment, designed for portable operation from batteries, indicates the thickness or resonant conditions by changes in an audible tone in headphones worn by the operator (Fig. 43).



(*a*) Basic circuit for thickness-gage operating on ultrasonic-resonance principle.

(*b*) Plate current as a function of frequency for ¼-in. steel thickness.

FIG. 42.—Ultrasonic-Resonance Testing. (Courtesy Branson Instrument Co., Stamford, Conn.)

The sonic resonant frequency of entire test objects is used for comparison of similar test objects with a standard known to be sound, in the sonic comparator (Fig. 44). It is assumed that identical bodies will have identical natural frequencies of vibration. The test object is vibrated by means of a transducer and stylus excited from a calibrated electronic oscillator. A wide-range microphone is used to detect resonant frequencies. Frequencies of vibration in the range from 100 to 10,000 cps are measured to an accuracy of the order of 1 per cent. Resonance is detected by a characteristic pattern upon the cathode-ray oscilloscope indicator. This method has been applied particularly to the nondestructive testing of grinding wheels, but conceivably could be used upon a variety of test objects.

FIG. 43.—Branson Audigage Ultrasonic Measurement of Corrosion Wall Thinning of Storage Tank in Service. (Courtesy Branson Instrument Co., Stamford, Conn.)

Triboelectric and Thermoelectric-Power Tests:

Triboelectric and thermoelectric-power tests are based upon the use of potentials developed through contacts with the materials of test objects. In triboelectric tests, use is made of the phenomenon which occurs when two dissimilar materials are brought into intimate contact with each other (as with rubbing friction) and then separated. Usually one material receives an excess of electrons (tribute) from the other, so that it is negatively charged, while the other material is left positively charged. The magnitude and polarity of such triboelectrification vary for different material combinations and have been evaluated in the "triboelectric series." In thermoelectric-power tests, use is made of the thermoelectromotive forces developed at junctions between dissimilar metallic materials, which can cause a flow of current in external circuits when such circuits are closed through two junctions held at different temperatures. This principle is well known in the use of thermocouples to measure temperatures. The magnitude of the net voltage, for given differences in junction temperatures, can be established for given combinations of two materials at the junctions. Both triboelectric and thermoelectric nondestructive tests involve the transport of electrons through potential barriers (at the surfaces between unlike materials) as their probing medium. Only the triboelectric method of nondestructive testing has been fully developed into a commercially available nondestructive testing instrument to date.

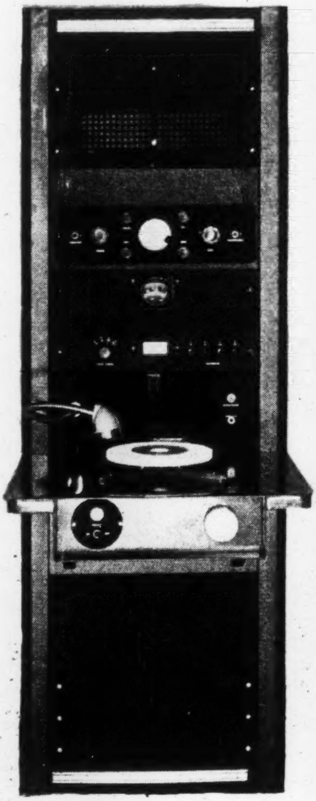


FIG. 44.—Saturn Sonic Comparator Used in Mechanical Vibration Tests of Grinding wheels. (Courtesy Saturn Electronics Co., Niagara Falls, N. Y.)

The Metalsorter (Fig. 45) employs a circuit which will detect minute quantities of electrical current generated when two metallurgically or chemically unlike materials are moved in frictional contact. If both conductors are metallurgically identical, no current will be generated. Occasionally, two unlike conductors will not generate a current of measurable magnitude. However, such conductors can almost always be distinguished from one another by comparing each to a third conductor and using the differential current value as a basis for separation. It should be noted that triboelectric polarity is a function of the metallurgical nature of the conductors and their connection with respect to the measuring circuit; however, the magnitude of the effect is not necessarily a function of the degree of unlikeness. Therefore, the triboelectric magnitudes and polarities of various conductors are obtained empirically. Since these values are all relative with respect to one another, the Metalsorter has been provided with controls for calibrating the instrument to fixed standard values.

The Metalsorter is designed for the sorting or identification of metal parts where not more than four chemically or metallurgically different alloy types are involved. Where more than four types are involved, it may be necessary to make two or three sorts with as many different selective test rods in order to accomplish complete separation. The test can be made on any metal part wherever a small area of clean, scale-free metal surface is available. It can be applied to slabs and billets as well as semifinished and finished parts.

Sorting can be done on either a basis of composition or structural differences. It is often possible to determine, in a relative sense, the differences in degree of cold work in sheet and wire products. A production testing fixture allows the sorting of small parts at a rate of 15 to 20 per minute.

Essentially, the equipment consists of a control unit and a portable sorting head which is connected to the control unit by means of a cable. The sorting head contains all the main controls for actuating the test and is designed for one-handed operation. A standard rod in the form of a bar of known alloy, $\frac{1}{4}$ by 3 in. long, is fastened into the sorting-head chuck. When the standard rod is placed on the piece to be tested, it completes an electrical circuit. Actuation of the test switch on the head energizes a solenoid which causes the standard rod to be reciprocated against the test piece, and a large electrical meter indicates the character of triboelectric effect produced. Both the sorting head and the control

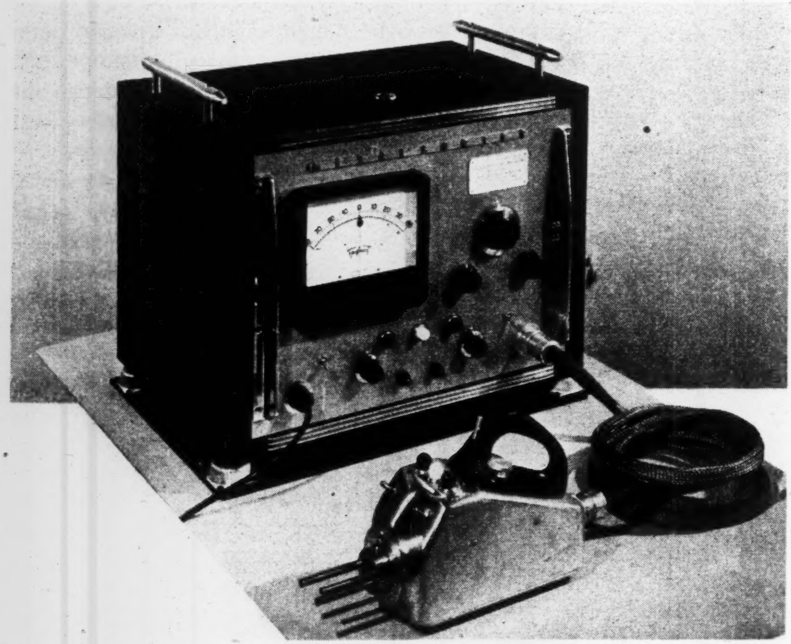


FIG. 45.—Doschek Metalsorter for Triboelectric Sorting and Classifying of Metallic Materials (Courtesy Doschek Associates, Inc., Crafton, Pa.)

unit contain signal lamps which also indicate the character of the test and eliminate the necessity of the operator having to view the meter after each test.

Present applications of the Metalsorter include sorting, inspection, and quality control in a wide variety of metal-producing and fabricating industries.

Spot Test and Other Chemical Tests:

Methods in which the test objects are subjected to any type of nondestructive chemical action are included in this class. Tests which are purely chemical analysis (and possibly destructive of the samples) and metallurgical etching procedures fall outside the scope of nondestructive testing, in most cases.

The two most widely used chemical tests are (1) chemical spot tests used to identify or measure some inherent characteristic of the material, and (2) chemical and electrochemical tests used, for example, to detect processing or material defects such as pinholes in protective coatings. In such tests, the chemical reactions involve transport of matter as well as the chemical energy of reaction.

Common examples of chemical types of tests include the well known sulfur-print technique which records the sulfur distribution in steel, and similar tests for revealing the distribution of phosphorus, nickel, lead, etc., in steels. These tests are used for sorting or quality inspection of steel blooms or billets. The corrosion resistance of stainless-steel welds has been chemically evaluated, as has the distribution of oxygen near the faying plane of pressure welds in steels.

Coating porosity tests include several which detect pinholes by chemical reactions with the base material beneath the coatings. Ferroxyl paper prints and electrographic printing have both been used successfully for this purpose.

SELECTING AND SPECIFYING THE PROPER NONDESTRUCTIVE TEST METHODS AND PROGRAMS IN INDUSTRIAL APPLICATIONS

The preceding examples and the basic principles which underlie them illustrate the nature and limitations of the available nondestructive test methods. Each method has specific limitations and specific application advantages for certain materials and inspection needs. There is no such thing as a general nondestructive test applicable to every kind of material, part, or structure, nor to all their functions or operating conditions. Instead, each nondestructive-test design must be based upon a thorough understanding of the nature and function of the part being tested and of the conditions of its service.

The engineer requires full information concerning the service loads and conditions of use to which a part is to be subjected in order to specify a useful nondestructive test. He also needs, from operating experience or destructive tests upon the part, clearly established limits of acceptability or rejectability, or at least a statement of the accuracy to which service performance must be predicted in order that the tests be useful. Furthermore, it is necessary to prove that the property which is to be measured by the nondestructive test is, in itself, a reliable measure of the strength or serviceability property to be predicted. In absence of such necessary data, it is not possible to specify intelligently a reliable nondestructive test.

The necessary data on service loads and conditions and the acceptability limits should be provided by the *designer* of the part or material to be tested and by the *stress engineer*. They are presumably fully informed as to the nature of the service conditions and the probable stress distribution. They may know the probable points of initial failure with the given design under operational loads.

The knowledge of the designer may be supplemented by destructive tests upon critical materials and components. The determination of the correlation between the strength or serviceability, and the defects or correlated properties to be measured by the nondestructive test, is usually a matter for a *materials or process engineer*. Often an extensive series of controlled destructive tests is required in order to prove that the correlation is a complete and reliable indication of serviceability.

Finally, the job of finding a sensitive and reliable method of measuring the correlated property nondestructively is the job of the *nondestructive-test engineer*. Unfortunately, it has been the practice all too frequently to assume that the engineer developing the nondestructive test would take on the functions of the designer, the stress engineer, and the materials or process engineer, in addition to the job of designing and developing suitable nondestructive tests. Many fine nondestructive-test developments have eventually proven worthless in industry because the designer and the materials engineer failed to contribute reliable data. The nondestructive test may have been developed to be a reliable and sensitive measurement of the property it was designed to measure. However, it would be unreliable if that property were not proved by previous destructive tests to be a good measure of strength or serviceability.

Even the well-established methods of nondestructive testing now widely used in industry are subject to limitations. Radiography, for example, may reliably reveal porosity, shrinkage, inclusions, dross, and misruns in castings, lack of penetration in welds, and similar defects. Few indeed, however, are the cases in which the actual load for failure under service conditions or the service life can be predicted quantitatively from the X-ray examination. This would be difficult to do even by destructively sectioning the parts.

Similarly, magnetic-particle inspection of ferrous materials reveals cracks and surface defects reliably. However, there are not very many cases in which the fatigue strength, or the load necessary to produce static failure, can be predicted from these data. It is generally sufficient, however, that the inspector know that a fatigue crack or stress concentration will lead to premature failure under repeated stressing, in order to reject the part for such service.

The engineer specifying or designing nondestructive tests should recognize certain geometric limitations in their scope and sensitivity. Some test methods require access to *both sides* of the part, material, or specimen which is under test. Other methods can be modified for use as "*one-side*" tests. Some test methods can be applied to parts of almost any shape or size. Others are limited to areas with reasonably flat surfaces or with constant thickness section. A few types of nondestructive tests are applicable only to specimens of exactly identical geometry. Other tests are limited, at present, to certain kinds of materials or to parts with definite thickness limits. Some nondestructive tests allow large areas or volumes to be inspected in a single operation. Other test methods require *scanning* of each small area suspected of being defective.

Especial care should be exercised in specifying the limits of sensitivity and accuracy required or expected in a nondestructive test. The sensitivity of every type of nondestructive test is limited. Sensitivity adequate for excellent testing on one part may be totally inadequate for another test object. In general, more sensitive tests require more elaborate equipment and cost more. The cost of developing a suitable nondestructive test, as well as the cost of the actual inspection with that test, must be considered in every application. Nondestructive tests which cannot be applied economically in the specific application will usually be abandoned.

A simple rule to guide the specification of nondestructive tests might be the assumption that it is not economical to require the nondestructive-test sensitivity to exceed the accuracy with which the magnitude and number of service loads are known, or the accuracy within which the design assumptions predict true stresses or performance. Alternatively, it might be reasonable to limit the sensitivity specified for the nondestructive test to a reasonable fraction of the variations in strength or serviceability corresponding to the tolerance limits acceptable in the production of the sound parts.

It is desirable to limit the number of functions or properties to be measured by the nondestructive tests to those of practical importance in production or service. For example, a particular part might be weakened for service by any one or by a combination of several possible causes. These might include improper material, wrong heat treatment, internal defects such as porosity, shrinkage, segregation, dross, inclusions, or external defects such as cracks, surface notches, defects in plating, and so on. No single nondestructive test should be expected to measure reliably all of these properties. Often a separate type of nondestructive test is required for each general type of defect or cause of weakening.

The same reasoning holds true for service damage. Corrosion, repeated stressing, wear, impact, surface destruction, and many other factors may contribute to service failures of parts which were originally sound. Usually a separate method of inspection may be required for each of the types or locations of service defects.

The interval between nondestructive tests for service damage may vary with the types of defects. If specific nondestructive tests for each of the causes of failure are pyramided into large, complex nondestructive tests, the costs would ordinarily be unreasonably high. The designer, process engineer, and operating engineer should determine which properties are of practical limiting importance in production or service. The nondestuctive test engineer should reserve for nondestructive testing only those properties which cannot be more economically or reliably controlled through other methods of process control or inspection.

Often, many causes might produce weakening of the part. If only a few of these particular types of defects have been selected for nondestructive testing, the correlations obtained between these nondestructive tests and the service performance of the parts may be poor (unless the other causes for weakening are controlled or accounted for). Suppose that a choice exists between alternative methods of nondestructive testing, one of which measures only one cause of weakening while a second measures several important causes of weakening. The latter test may be more reliable on the whole, even though it is less accurate or sensitive in certain measurements than the former test.

EVALUATING THE RELIABILITY OF NONDESTRUCTIVE TESTS

Most nondestructive tests, as illustrated in the preceding examples, detect and evaluate flaws or defects, or determine strength and serviceability, by *indirect procedures*. These usually involve the measurement of a different but correlated property. Nondestructive proof of the existence of a flaw or defect is one thing. Measuring the influence of that flaw or defect upon the strength or serviceability of the test object is quite another. This latter determination must ordinarily be made by destructive tests on specimens both free of flaws and containing flaws, of each basic type, in each critical location. In nearly all fields of engineering materials, there is a serious lack of specific information on the influence of material and fabrication defects upon strength or serviceability. The nondestructive test cannot supply this knowledge. Such information should be obtained from destructive tests or from operating experience.

A necessary prerequisite to a reliable nondestructive test is a *proven* correlation between the property actually measured by the nondestructive test and the strength or serviceability property being predicted from the measurement. In situations where such correlations have not been fully established, or where several factors influence the relation between the measured property and the property being predicted, evaluations based upon the experience and judgment of skilled interpreters become a vitally important feature of a nondestructive test method. Such correlations are usually implied, but seldom proved or demonstrated, in patents, advertisements, and some technical articles which provide information to the administrative engineer. To obtain the necessary data to establish these correlations, and then to design and develop a reliable nondestructive test method based upon such correlation, is usually difficult and frequently costly.

Failure to demonstrate the reliability of such correlations before applying and believing nondestructive tests can be far more costly. This element of doubt, based upon lack of specific knowledge, has cost American industry millions of dollars. In most cases of doubt, inspectors using nondestructive test methods tend to be conservative, particularly in the absence of reliable service data. In all too many cases, parts rejected because of defects revealed in the nondestructive tests have shown no weakening because of the defects when subjected to proof tests. Millions of dollars worth of aircraft parts and thousands of man-hours of labor were wasted in the aircraft industry during the last war. This resulted from radiographic rejection of castings and forgings on the basis of arbitrary standards. Such standards were frequently established more by fear than upon careful physical tests. Such misuse of nondestructive tests cannot be justified economically in peacetime industry.

In evaluating nondestructive test methods, it is important to discriminate between the *reliability of the test method* (in revealing flaws or defects and in measuring the physical properties of test objects) and the *reliability of the judgments of the inspectors* (based upon the evidence revealed by the nondestructive method).

Lack of specific data, operating experience, or good judgment, may seriously influence the inspector's conclusions. This may occur even when the nondestructive test method is providing excellent data concerning the condition of the test object. Consequently, it is seldom good economy to place useful nondestructive testing equipment in the hands of unskilled laborers or inspectors with little inspection experience or with poor judgment. The combination of good data concerning the test object, provided by the nondestructive test, and good judgment on the part of the inspector is essential.

The inspector must evaluate the data concerning the test object in the light of the service to which it will be subjected. He must have full regard for experience obtained during operation of similar test objects under this same service condition. It is particularly dangerous to extrapolate conclusions from one service condition to new and completely different service conditions. Each case is specific. Generalizations are hazardous in most applications of nondestructive testing.

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GILLETT MEMORIAL LECTURE

THE GILLETT MEMORIAL LECTURE is sponsored jointly by the American Society for Testing Materials and Battelle Memorial Institute in commemoration of Horace W. Gillett, the subjects of the Lectures to pertain to the development, testing, evaluation, and application of metals.

This first Lecture was presented at the Fifty-fifth Annual Meeting of the American Society for Testing Materials. Others will be delivered annually at a meeting of the Society.

HORACE W. GILLETT

1883–1950

FIRST Director of Battelle Memorial Institute and Chief Technical Adviser from 1934 until his death. Originator and Editorial Director of "Metals and Alloys." Active member of the American Society for Testing Materials.

MAN, METALS, AND POWER[1]

FIRST GILLETT MEMORIAL LECTURE

BY NORMAN L. MOCHEL[2]

"Whosoever will be great among you, shall be your minister; and whosoever of you will be the chiefest, shall be servant of all."

President Fuller, members of the Gillett family, our very welcome guests from abroad as well as those from home, Dr. Williams and all Battelle people past and present, fellow members of the American Society for Testing Materials, ladies and gentlemen:

The feeling and the interest created by this occasion are apparent from the goodly numbers before me and around me.

The occasion may be termed momentous. By this hour, we initiate a new feature into the activities of our Society, an annual item that is to carry on for at least twenty years. Battelle Memorial Institute and the American Society for Testing Materials have joined in the establishment of a memorial that, through the medium of an annual lecture, they might commemorate and reflect dignity and honor on the name and the achievements of Horace W. Gillett. We are gathered here at this hour, during a busy annual meeting, our Fiftieth Anniversary meeting, for this purpose.

It is very fitting, for a host of reasons, that Battelle Institute and our Society should do this.

A Semitic psalm written probably some 3300 years ago, and with which I am sure many of you are familiar in its more modern phrasing, teaches us that:

"Time, like an ever-rolling stream,
Bears all its sons away;
They fly forgotten, as a dream
Dies at the opening day."

And down through the ages man, in his saner moments, has realized how true this can be. At times he has resented it, and at times he has done something about it. Our being here today is for the latter purpose.

Great leaders and progressive movements of church, state, and society have all too well recognized how easy it is for us to forget. "Lest ye forget" is a common cry of concern through all ages; we hear it every day. It has expressed itself in countless monuments, in buildings, in places, in holidays, in memorial services, and even in memorial lectures. These are fit emblems or gestures, both in reverent memory of those or that for which they were established, and in loving gratitude and appreciation on the part of those who arrange them. And we should remind ourselves that there is a third and maybe the most important consideration to such emblems and gestures—they are really created for the living, that the values of the life that has passed may continue to enrich the lives of those still carrying on; that the reverence, love, and appreciation of persons and things past may bear their proper influence for good as time goes on.

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[1] Presented at the Fifty-fifth Annual Meeting of the American Society for Testing Materials, June 23, 1952, New York, N. Y.

[2] Vice President of ASTM; Manager, Metallurgical Engineering, Westinghouse Electric Corp., Philadelphia, Pa.

And so it is here—the many friends and fellow-workers of Dr. Gillett at Battelle Memorial Institute have a deep desire to keep alive, over a useful span of years, their own deep love and admiration for this man. What he was to many of them will always remain green in their memories. And they desire to share these memories, with all who will just pause each year, to do honor to Dr. Gillett and benefit themselves by so doing.

I believe it was fitting that our Society should be selected as the keeper of this trust and this responsibility. Our Society is honored in this way, and in turn our Society renders honor to one who served it and its purpose so well.

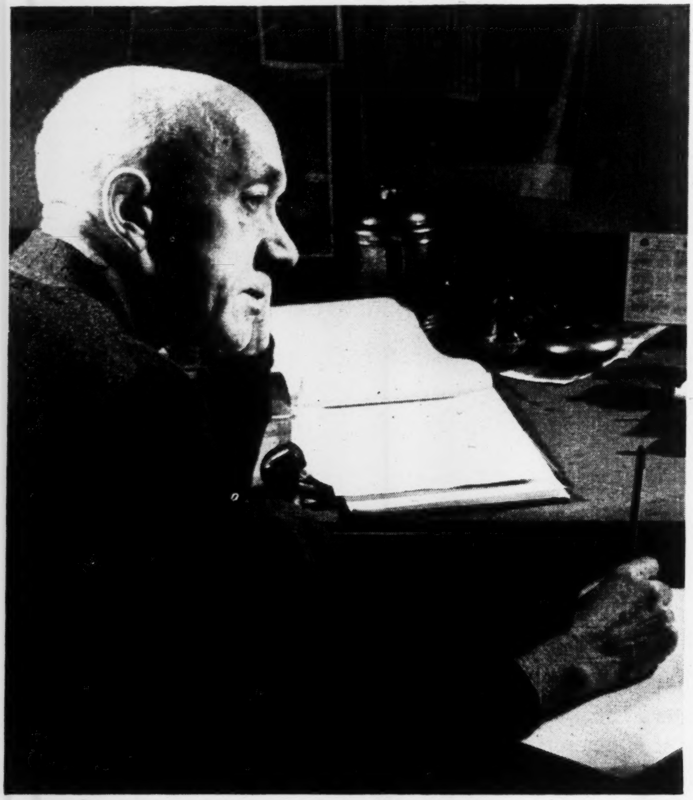

FIG. 1.—Dr. Horace W. Gillett.

As one might readily suspect, Dr. Gillett was a member of many technical organizations and honorary societies. The following may be listed:

American Society for Testing Materials
American Institute for Mining and Metallurgical Engineers
American Society for Metals
American Foundrymen's Association
Electrochemical Society
British Iron and Steel Institute
British Institute of Metals
AmericanChemical Society
Sigma Xi
Alpha Chi Sigma

Quite often, technical and scientific men are members of many organizations and busy in varying degrees in their activities. It is not uncommon for such organizations to appeal to individuals in different ways. A person may well have deeper experiences in one than in another. Usually he will put more into one than into another, and consequently will get more out of it. I know from my own contacts, and from talking to many at Battelle, that there was something about the ASTM, its members, its way of doing things, that appealed to Dr. Gillett—in short, I think he was more at home with us.

For many years, we had his attendance at our annual meetings and in many committee meetings. At times, he served as a member of:

Committee B-2 on Non-Ferrous Metals and Alloys
Committee B-6 on Die-Cast Metals and Alloys
Committee A-5 on Corrosion of Iron and Steel
Research Committee on Fatigue of Metals (subsequently Committee E-9 on Fatigue)
Joint Research Committee on Effect of Temperature on the Properties of Metals

We enjoyed his striking personality, his keen interest, and we profited by his calm judgment and friendly advice. We have missed these in recent years; we do well to try to recapture these in spirit and memory.

It is a great honor to be privileged to deliver this first H. W. Gillett Memorial Lecture, and this person deeply appreciates that honor. Too well has he experienced the many responsibilities that accompany the honor. It is with deep humility and a sincere purpose that he has approached this hour.

The presentation of today may well not meet the ideas of many as to what a memorial lecture should be. Those that follow will be, no doubt, technical and scientific masterpieces. They will be rendered by the most eminent men of their time. But as the years roll on, inevitably there will come the time when Gillett lecturers will, of necessity, have to announce that they knew not Dr. Gillett, except by hearsay or from the record. For this and many other reasons, it was agreed by all who were parties to these arrangements that this beginning of the series well could and should devote more of its time and space than is customary in memorial lectures to dealing with Dr. Gillett himself, what he was, what he did, and thus possibly place on record many things that may be of some service to those who follow.

BRIEF BIOGRAPHY

Horace W. Gillett was born on December 12, 1883, in Steuben County, N. Y.

He was graduated from Cornell University in 1906 with an A.B. in chemistry. He remained at Cornell teaching physical chemistry and electrochemistry until 1910, when he received his Ph.D.

During his summer vacations, he was active, being employed by Thomas A. Edison and Arthur D. Little in their well-known laboratories. These must have been valuable experiences for any young man in those days.

From 1910 to 1912 he was manager of the Aluminum Castings Co. at Detroit.

From 1912 to 1924, he was Chief Alloy Chemist of the Bureau of Mines, in charge of the field station at Ithaca, N. Y. After World War I he received several financially attractive offers to undertake industrial research work, which would have taken him away from Ithaca. He did not accept, simply because he liked Ithaca, and the hunting in the surrounding hills, and because he felt that Ithaca was a good place to raise his family.

But in 1924, an opportunity more to his liking opened up, and he went to the National Bureau of Standards, as Chief of the Division of Metallurgy.

In 1929, he started the technical magazine, "Metals and Alloys," becoming Editorial Director, and that same year he took the position of Director of Battelle Memorial Institute.

In 1934, he became Chief Technical Adviser at Battelle, which position he held till his passing from this life on March 3, 1950.

"MAKER OF MEN AND METALS"

People referred to and addressed Horace W. Gillett in many ways. To some, he was always Doctor Gillett—this title of respect was his, and many did not presume to pass beyond nor around it. But this, I am sure, was never by his will.

Just a few months ago, in a book review appearing in a British technical magazine, a reviewer, whose name was not given (although we might well guess his name) referred to Dr. Gillett as "this Grand Old Man of American Metallurgy." We appreciate deeply the affection from this friend across the Atlantic, that is apparent in this way of referring to Dr. Gillett.

There is, in these United States, a somewhat vague, metallurgical position, or assignment, which few men have filled. No one can make application for it. There is some doubt, always, as to when, and where, and by whom the assignment is made. And only one person may fill it at a time. Many of you will recognize that I am referring to that title or position which we lovingly call the Dean of American Metallurgy. Opinions may vary at times as to those who have rightfully held this most important place in our hearts and minds. I do not believe that anyone here will object to my saying that four men who had rendered valuable service in the work of our Society were held by their associates as having reached this honorable position. I refer to:

Henry Marion Howe
Albert Sauveur
William Campbell
William H. Bassett

And for a good many years past, there has been a growing realization that the name of Horace W. Gillett should be added to this list.

The speaker has been very fortunate to have known and to have been associated in some measure with the last four of these men. One realizes that it takes more than mere technical knowledge or ability to reach this select circle; it takes also a desire to search for truth and understanding, ability and desire to know and appreciate people, and an ever present urge to serve and help others.

Some few years ago, the late Major R. A. Bull, impressed by the work being done by Dr. Gillett, added this rather beautiful tribute—Horace W. Gillett, Maker of Men and Metals.

But to many of us, as we came to know him better and could enter upon a closer friendship, there was a very short yet endearing way in which we addressed him and referred to him—it was just "Gil" (Fig. 2, see p. 690). And "Gil" he will remain to many of us, so long as we have memory.

PEOPLE, PLACES, RECORDS, MEMORIES

Some who have known Gil longer than most others feel that much that was Gil went back to his professor at Cornell University, Dr. Wilder D. Bancroft. His style appeared to follow that of Bancroft, more than any other. It is worthy of note that Gil prepared a paper in 1932 on "American Contemporaries—Wilder D. Bancroft." This paper is well worth the time of reading.

At the time that Gil left those hills above Cayuga's waters, there was not the division between chemical and metallurgical activities that we usually find today. In those days, to many chemists fell the duties and the responsibilities—yes, and the opportunities—that metallurgically trained personnel have today. Upon leaving the ivy halls, Gil veered towards metallurgy almost at once. His writings plainly show the trend. Ceramics for foundry purposes, pyrometry, the melting of metals, and furnaces in which to melt them quickly became the points of his interest.

During the 1912 to 1924 period of service with the Bureau of Mines, Dr. Gillett has left records of some forty publications. Quite early in the period, one article dealt with "The Chemist and Scientific Management"; but otherwise his writings were of metallurgical character.

Thus, one is not surprised at the move to Washington to the National Bureau of Standards in 1924, as Chief of the Division of Metallurgy. One cannot speak too highly of the five years that Gil devoted to the work of the Bureau. His own reputation grew rapidly during these years, and by 1929 he was widely acknowledged as one of the nation's outstanding metallurgists.

There was a veritable renaissance in the subject of metallurgy in Washington. A host of new studies were undertaken, and with a new vigor. One might mention such things as high-temperature creep tests, some of the very first made in this country; studies on high-speed steels and machining of metals; hardening and hardness; studies on wear; gases in metals; foundry investigations; metallography; embrittlement. These are but a few.

Equally important was the fact that many people were attracted to the Bureau. It became a center of metallurgical thought and standardization. Industry brought its problems to the Bureau and was not disappointed. To those workers already at the Bureau were added many others, attracted by the high quality of the work being done and intrigued by the opportunity to work under the dynamic leadership that was to be found there. The names of Cross, Digges, Ellinger, Epstein, Freeman, French, Herschman, Jordan, Quick, Rawdon, Rosenberg, Saeger, Scott, Tucker and others come to mind as we think of those days. Many of these have, of course, left the Bureau and have made their marks elsewhere, and with distinction.

And then came 1929 when Gil launched out into two new ventures. Either was a task in itself. You will recall those days of promise in 1929—that were soon to turn into the depression years of the early 30's—difficult years for new ventures to hold on and prosper.

In that year, Gil started the technical magazine, "Metals and Alloys," now known as "Materials and Methods," and became Editorial Director. As an editor, Gil belonged to the old school. Each issue must have his page. Many readers turned to it first. He held to his rights, and to his responsibilities, to freely praise, or to freely criticize, to warn, to chide, to cheer, to despair, and to call to his readers' attention items that he felt were timely. He was thoroughly honest as he saw things, and he was accordingly fearless. He loved honesty and hated sham. He made many friends, although at times temperatures went up a few degrees. Between 1929 and 1942, some 220 of his editorials appeared. They provide a most interesting record, and I hope that the Society places this list on record.

In 1929 Dr. Gillett also became the Director of Battelle Memorial Institute, located in Columbus, Ohio. The story of Battelle Institute, its origin, its remarkable growth, its present position, and its world-wide plans for the future are not my subject for today. But we know that the names Gillett and Battelle are in-separable; we cannot mention one without the other. A splendid building had been erected by the founders. An organization was in operation which was inclined to operate on Battelle funds only. It was a pioneer organization, housed and ready for a dynamic directorship. Gil had a dream. He wanted to make Battelle available and of real service to industry; he wanted research men from industry at Battelle. It was to be of service to all, big and little. Here, the little company, without research facilities, could have a laboratory and its own man, or an assigned man, at work on its problems. And here too, in time of need, could come the biggest company of all—the Federal Government.

And just as had happened five years earlier at Washington, so to Columbus came many experienced men, and many new minds, to work with Dr. Gillett and to make his dream come true.

Nursing both "Metals and Alloys" and Battelle Memorial Institute through the depression years, carrying at the same time a heavy load of research work, turning out a large number of metallurgical papers, editorials, and writings, and being of help and inspiration to so many was an enormous labor. This taxed even Dr. Gillett's unusual stamina and ability. But he came through; both ventures were well started on their ways.

And then 1934 and another change. Voluntarily on his part, and against the opposition of many friends, he gave up the directorship and assumed the position he preferred—Chief Technical Adviser. Gil's first love was research rather than administration. He preferred the technical above all; he was rather sensitive at times to the confinements of administration. He regretted occasionally that some of our best research minds had gone over to the executive branch.

Now let us not get the impression that Gil was not a good administrator; his record shows otherwise and he did seem to enjoy a certain amount of it. One of his pet executive ideas was a system of cost accounting which he installed in the Division of Metallurgy at the Bureau of Standards. He wanted to know what each research project cost. Out of Gil's system grew the present cost-accounting system of the Bureau of Standards, which many feel is outstanding among those of governmental research agencies.

He was always around, strolled everywhere, knew everyone—and everyone knew him—or nearly everyone. There was the day when a sweet young lady at Battelle looked up, saw Gil, and asked him to empty the waste paper basket—and he did. He was always interested in what was going on and seemed to be able to smell out that which needed attention.

He was cost minded, as every engineer must be. A favorite expression when anyone objected to costs was, "You've got to break a few eggs if you want to make an omelet." On the other hand, if he saw waste of manpower, he had another favorite expression: "I've never seen eggs hatched out any faster with two setting hens on the nest."

His favorite greeting when you entered his office was, "What's new?"

He was patient with young engineers. His doors were always open, and many went there regularly. He was always ready to stop and talk to young and old. He loved people and loved to talk to them. The days were always too short.

He used the power-of-suggestion system, hardly ever force or orders, and thus had the ability to make his administration more effective. And of course, some had to learn that his suggestions were really meant to be considered, that they were not idle conversation.

Does this not sound like a good executive?

Gil, looking ahead at this thing he had started, saw the necessity for some energetic, enthusiastic administration. He feared that this job ahead might confine him and prevent him from doing those things that he most wanted to do and what he thought he could best do. Of course, he was the "boss"; he could have done what was to his liking and relegated to others the things he did not like. But we all know that was not Gil.

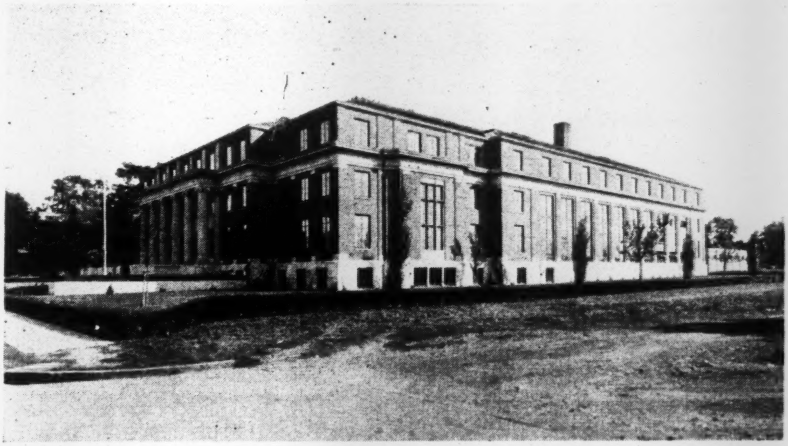

FIG. 3.—Battelle Memorial Institute—1929.

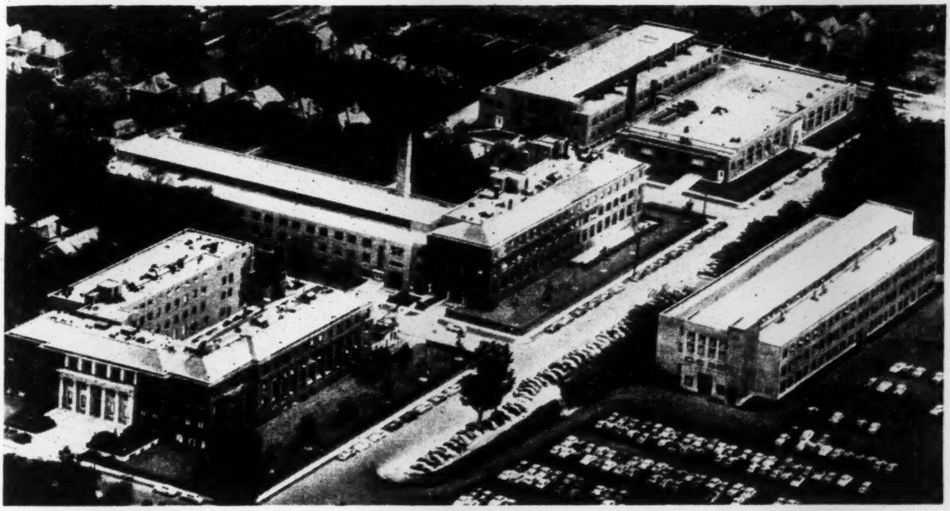

FIG. 4.—Battelle Memorial Institute—1952.

Since 1916 he had held a close friend and admirer, and later a loyal assistant, in the person of a young, energetic metallurgist, Dr. Clyde E. Williams, Associate Director at Battelle. For the big job ahead, Gil felt that Clyde Williams was the man to do it, not as an Associate

Director but with the full force and prestige of the Director's position. I know that Dr. Williams fretted and objected more than any other, but Gil had his way. And how right Gil was as one looks at the results—Battelle today. "Research in Action," someone has called it, with its more than 12 acres of laboratories, 38 research divisions, over 1600 staff members—and it is still growing.

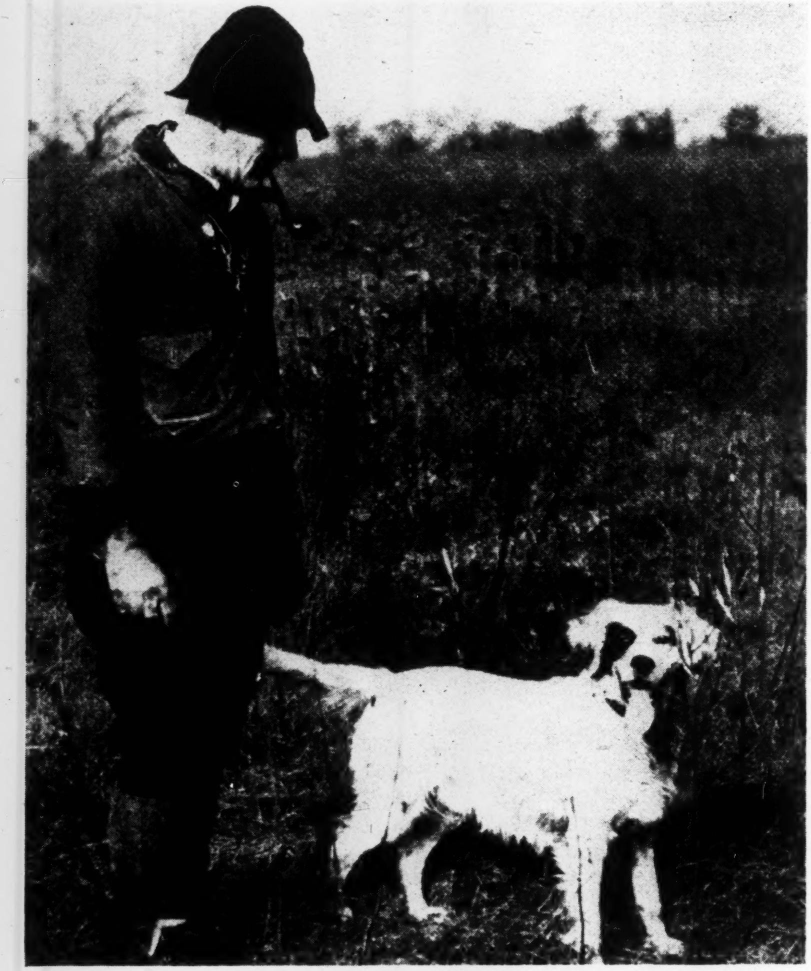

FIG. 5.—"Gil" and "Flash."

All who knew Gil well knew of his great hobby—his dogs, English setters. He loved to hunt—as a true sportsman—and to raise and train his own dogs. He was well known both in England and in this country in this field. He had been able to trace the pedigrees of his English setters far back to English ancestors among the early Laveracks, Llewellins, Mallwyds, O'Lecks, and others. He was always ready to talk about dogs. Although not an expert on dogs, I quite often sat at his feet and listened, when I would drop in at Battelle

I have not been able to verify it, but I think that Mrs. Gillett must have helped to train "Flash" (Fig. 5). Flash often accompanied Gil to work. He would lie quietly all day long, seeing all, dozing, and just satisfied to watch Gil as only a loving dog can, until 4:50 p.m. Someone had trained Flash that 4:50 was quitting time and that, since Gil never knew when to quit, he had to be reminded. Battelle people still laughingly talk of the intelligence, the persistence, and the antics of Flash in telling Gil that it was time to go home. And always, he finally succeeded.

Dr. Gillett was a prolific writer. What is supposedly a complete list of his writings, supplied by Battelle, is appended. His first releases were in 1907–1908–1909. From 1911 to 1950 not a single year passed without one or more publications. The year 1930 was the high point, with 14 publications. In all, there are 174 papers, 3 near books, 3 books, and 13 patents in the list. I am sure the list is not complete, because I know of other writings that should bear his name, where credit has been otherwise given by Gil himself. The wide coverage of metallurgical subjects is amazing and stands as a monument to the ability and vision of this man.

Gil very often used his conversational style of writing to advantage. He did not hesitate to use a common figure of speech, no matter how high-brow or sedate his audience, in order to put his point across. As someone has aptly put it, he wrote to communicate.

Gil collaborated with E. L. Mack in his first book in 1925 on the subject, Molybdenum, Cerium, and Related Alloy Steels." This book was timely and was a masterpiece of technical compilation, of both published and not previously published data. The first paragraph of the Preface merits attention:

> "This book is based on the thesis that a given alloy steel is a member of a class rather than a special entity and that with due regard to required heat treatment it is often possible to produce, by combination or substitution of alloying elements, several chemically different steels which are practically interchangeable for the same engineering application."

I think we can recognize the vision in this simple statement and realize how in recent years, with critical shortages of alloying elements, we have leaned so strongly on this basic idea.

Self-effacement was most marked in Gil's way of doing things. He always put the name Battelle first, ahead of the name Gillett. It was Gillett who prepared the first draft of the Fourth Edition of Bullens' "Steel and Its Heat Treatment" in 1938, and it was Gillett who carried out the final selection and arrangement. And likewise, in 1948, for the Fifth Edition, Gil was responsible for the final selection and arrangement. The books are marked as to authors—D. K. Bullens and the Metallurgical Staff of Battelle.

Likewise in 1941 appeared a book, "Prevention of the Failure of Metals Under Repeated Stress," by the Staff of Battelle Memorial Institute. You must read in the fine print that the first draft was prepared by H. W. Gillett.

One book, "The Behavior of Engineering Metals," published in 1950, after he had passed on, bears the name of H. W. Gillett. Gil had completed the manuscript—it was his intention here again to give full credit to the Staff, but the Staff decided otherwise and recorded this book in his name.

A book review, appearing in a British technical paper, ends in such a way that I believe it bears repeating:

> "This book is quite easy to read, but, although the author gives excellent data on the behavior of engineering materials, he leaves the engineer to make his own choice of an alloy for a specific purpose."

How well this reviewer stated the case. Gil did believe in putting the complete data before the engineer and giving him all the advice and help possible, but he did not believe in assuming the responsibilities or right of the engineer to make his own selection.

Dr. Gillett was honored in many ways. In 1932 he received the McFadden Medal of the American Foundrymen's Assn. In 1939, he delivered the Henry Marion Howe Memorial Lecture before the American Institute of Mining and Metallurgical Engineers, using the interesting and timely subject, "Some Things We Don't Know About the Creep of Metals." In 1942, he was invited by the Institute of British Foundrymen to deliver the Fifth Edwards Williams Lecture, and he used the important subject, "Foundry Teamwork." In 1944 he delivered the Second Annual Foundation Lecture before the American Foundrymen's Assn., using the subject "Cupola Raw Materials." In 1948, he received an Armed Forces Certificate of Appreciation for many valued wartime services.

Dr. Gillett had remarkable capabilities for turning out work of all kinds. It has been recorded that in 1947, Gil read 2280 manuscripts of Battelle technical reports, and in 1948 he read 1900 reports. For each report read, he managed to write a brief abstract. He was a pioneer in abstracting work, and his services were much sought and freely given. He had an excellent memory, remarkable reading speed, and an amazing ability to withstand frequent interruptions and to pick up where he left off with no loss in thought or action.

If one takes the time to read forewords and prefaces in the well-known Alloys of Iron Research Monograph Series, he will discover that Dr. Gillett not only served on the main committee but that he rendered valuable aid to many authors. At least one of the volumes was prepared at his suggestion. In one appears a note, so true of Gil at all times:

> "Useful data that might otherwise have been missed have been unearthed by Dr. H. W. Gillett."

I am sure that my friends of the Joint ASTM-ASME Committee on the Effect of Temperature on the Properties of Metals would never forgive me if I did not say a word relative to his years of service in and to that group. Dr. Gillett became a member of the Joint Committee in June, 1930, and resigned in November of 1945. No member was more active nor more interested.

Many will recall that in 1930, while still early in his Battelle and his "Metals and Alloys" work, he was asked to head the 1931 Symposium of the Joint Committee, held in Chicago in June of that year. Here he set a standard for such meetings that has been copied elsewhere by many. Twenty-eight papers and an extensive bibliography, all completed and preprinted in a paper-bound volume in advance of the meeting, were presented in two parts by experienced abstracters so that the two sessions could be devoted almost wholly to discussion, and the whole republished in the same year in a clothbound volume of 829 pages, complete with all discussions.

And in 1941, the Committee had collected a large amount of data and information on the effect of low temperature on the properties of metals. Fourteen sources supplied the data. What should be done with it? That was simple—it was just turned over to Dr. Gillett and from it came an excellent 112-page booklet, "Impact Resistance and Tensile Properties of Metals at Subatmospheric Temperatures."

Again during World War II, through the initial suggestion of the Joint Committee, the War Production Board sponsored a program at the University of Kentucky on the Behavior of Ferritic Steels at Low Temperatures. Dr. F. T. McGuire was the official investigator. A tremendous amount of data became available and again Dr. Gillett, with his unusual abilities in such a situation, was called upon by the War Metallurgy Committee of the National Research Council to prepare the rather voluminous report.

Gil was always an excellent reporter. He set a standard for report writing that has become the standard at Battelle, and elsewhere. All the facts must be reported. In 1948 there appeared a little book, "Copper as An Alloying Element in Steel and Cast Iron," by Lorig and Adams of Battelle. Dr. Gillett prepared a foreword and closed it with these words:

> "Like all men and all materials, copper steels have their limitations and drawbacks, which are equally as important engineering facts as those which bring out the advantages. This book tries to present both kinds of facts in the hope that sensible utilization may be made of an alloying element still not fully appreciated."

These few words, written quite late in life, tell us much of Gil and his philosophy.

Gil was a rugged individualist. He believed in men and their freedoms. He recognized the place of government, and his records show how well he served it at all times. But Gil was plain spoken, too, as are many others, when he felt that those in power had gone too far down the road to that which we call the "left."

Time does not permit my saying all that I should like to say. But I am sure that each of you, who really knew Gil, has treasured away golden memories in heart and mind that transcend any thoughts that my poor words have tried to express today.

THE USE OF METALS

It is a requirement that a Gillett lecture shall deal with the development, testing, evaluation, or application of metals. Gil did all four of these well. He was more inclined to the practical, yet he could and would trade ideas with the most theoretical. Development, testing, evaluation—these were only necessary steps to useful service or application.

The very important position of metal application today is well shown by a recent statement of the Department of Commerce that in the many billions of dollars of unfilled orders in this country 85 per cent were for metal products.

Of course we recognize that a very great part of this must be listed as being for military purposes. Man used metals to make his tools, by which he emerged from savagery, and with these tools and more metals he built those machines that have given a greater hope to human life. But we must also remember that the sword came before the plowshare, and the spear before the hammer and chisel. What was obviously to be a blessing has always been a curse. We seem not yet to have mended our ways. And our more recent developments, involving atomic reaction, have followed the same pattern: darkness and fear and despair first, brightness and hope later.

It has been said that "the Creator gave to Man materials from which he, Man, could fashion his destiny."

One could speak with much pride and feeling on the application of our metals to many and varying fields of modern endeavor. They all have their important places in that which we term our modern civilization. They fit together, like a jigsaw puzzle: each depends on another to round out the whole. Some could not exist without the others.

MANUFACTURED POWER

I would deal for a few moments today with the application of a goodly number and a fair quantity of our metals to a purpose that is truly great by reason of the service it renders. If we would attempt to evaluate the influences exerted on the human race, and consider only developments along material lines, leaving out those of a moral or spiritual nature, there are few indeed that can come even close to matching the importance of the manufacture, distribution, and use of readily available, relatively cheap electric power. Manufactured power is a part of our very existence and of our survival. It is the matter of great promise for the years of peace; it is the necessary bulwark in time of preparedness and conflict.

This year of 1952 noted an anniversary of great importance to all of us. In several places, there was formal recognition of the 200th anniversary of the famous kite experiment carried out by Benjamin Franklin in Philadelphia, the headquarters of our Society. Franklin did a lot of things relative to electricity. Yet it was not until more than 125 years later that the business of generating and distributing electricity emerged as a new enterprise. Yet in these last 75 years, which have seen the development of so much in the field of engineering, I know of nothing more important.

When Dr. Gillett first saw the light of day in 1883, central stations for street lighting purposes were but a year old. That year of his birth saw the Frenchman DeLaval secure his first patent on a steam turbine. Parsons, in England, built his first turbine, of 10 hp capacity, the next year. Before Gil entered Cornell, the great debate on direct current *versus* alternating current had been completed, and the value of the latter well established. The years 1900 to 1902 saw the building, installation, and operation of the first real central station turbine in this country, a 2000-kw unit at the Hartford Electric Light Co. Gil was just entering Cornell at that time. As we have already stated, he spent some of his summers in the laboratory of Thomas Edison and so early came in contact with electrical development. Thus the application of manufactured power of which I speak actually took place during the lifetime of Dr. Gillett. He saw it all; directly and indirectly his work was of great value to this application.

Incidentally, we should note that ASTM, at this very meeting, is also marking its Fiftieth Anniversary, having been incorporated in that same year of 1902. It, too, has served the field of application of which I would speak, through its entire lifetime.

I would now, if you will, ask you to go on a little journey with me. I want to take you to a modern power plant. I am sure it would interest you to go to one of those new outdoor stations where everything is out in the open, under the sun, the moon, the stars, and in the rain (Figs. 6 and 7).[3] At this particular station, you would see two 60,000-kw units at work. Red-painted steel construction indicates extension of the plant with two more units. But since this plant is in Texas and since we have other meetings tomorrow, perhaps we should stay closer to home.

Let us just drop down the kill between Staten Island and New Jersey to a place known as Sewaren, N. J., and use the comparatively new station there for our visit (Fig. 8, Plate A). As we approach it, I would point out that there is a great deal of civil, electrical, mechanical, chemical, and metallurgical engineering

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[3] Security limitations have prevented printing these illustrations which were shown at the time of delivering of the lecture.

PLATE A

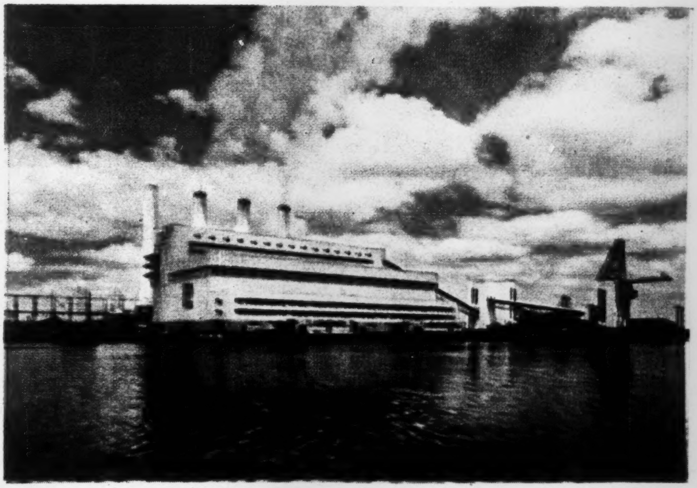

FIG 8—Sewaren Generating Station, Sewaren, N.J. Public Service Electric and Gas Co.

FIG. 13— Inside View, Turbine Floor. Sewaren Generating Station.

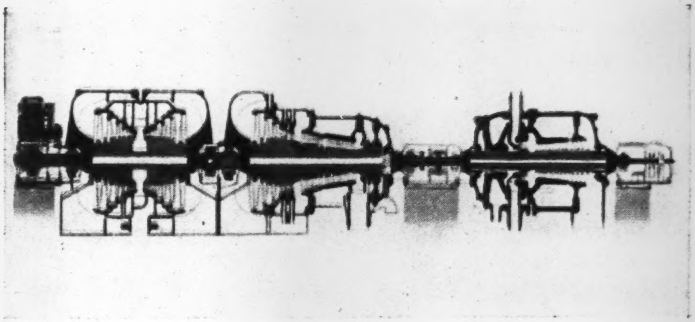

FIG. 16—Triple Exhaust, Single Shaft 3600–rpm Turbine.

wrapped up in this beautiful station. It is the work of many minds and hands. And there are many ASTM standards and other ASTM activities represented here. The work of practically all of our A and B committees, many of our C and D committees, and many of our joint committees with other societies is used in the building and operation of a modern power plant.

As we enter a modern power plant, we will find many items of major equipment, and numbers of smaller items. Any one of them offers an interesting development history, and all entail metallurgical development.

Everywhere, it appears, are pipes of all sizes and valves and fittings of every description, all going somewhere.

Figure 9 shows a modern boiler, or steam generator as some call it, such as we will find in central stations. We will be impressed by its size, and the great quantities of pipes and tubing. The one illustrated here is as tall as a 12-story office building. Boilers now supply steam up to 2400 psig and with temperatures up to 1100 F. One can imagine the tremendous amount of steel of every form that this giant requires. Into this field of manufactured power has gone some of the best work of Committee A-1 and the Joint Committee on the Effect of Temperature on the Properties of Metals. A Boiler Code prepared and maintained by The American Society of Mechanical Engineers has become the law in most states. Our Society works closely with this Committee responsible for this Code and supplied the specifications for materials and test methods.

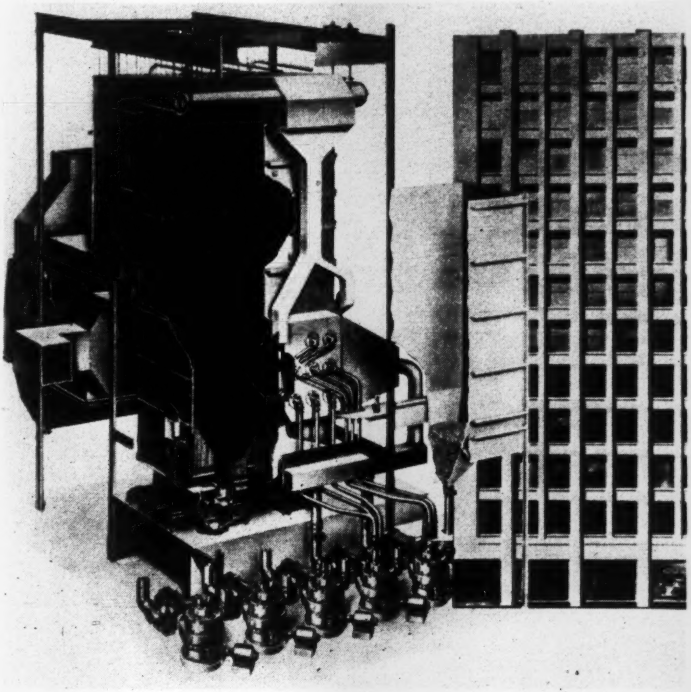

FIG. 9.—Modern Central Station Steam Generator.
(*Courtesy Babcock & Wilcox Co.*)

We might also take a glance at the

large surface condenser in the basement and remind ourselves of the many thousands of alloy tubes in it and recall the service rendered by our Society in the early 20's in effecting standards for condenser tubes that have stood the test of time (ASTM Specification B 111 - 51).[4] Figure 10 illustrates a modern surface condenser.

Dust collectors,
Fly ash conveying system,
Electric precipitators,
Ash handling system,
Fuel systems,
Water intake screens,
Water treating equipment,
Oil purification equipment, and many other items necessary to plant operation.

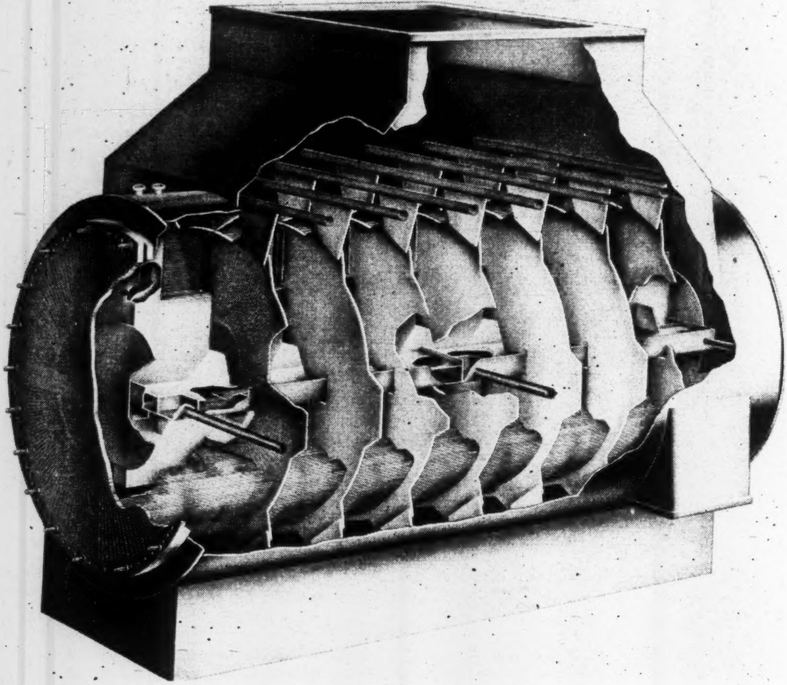

FIG. 10.—Cutaway Central Station Surface Condenser.

We could take time to look at any of the following interesting items:

Circulating water pumps,
Condensate pumps,
Feedwater heaters,
Boiled feed pumps,
Air removal equipment,
Forced draft fans,
Induced draft fans,

Then it might dawn on you that I was hurrying you just a little to get you up to the turbine floor—up to the place where the very heart of this live organization is taking the steam and turning it into power that can be sent out, here and there, for all to use.

On the way up in the elevator, I shall show you two older pictures. The first is that of the 2000-kw turbine-generator unit at Hartford in 1902 (Fig. 11). The second is that of a unit installed at the Richmond Station of the Philadelphia Electric Co. in 1935, which marked a high point in turbine development (Fig. 12). This is the largest single shaft unit of the 1800-rpm type ever built. It develops 165,000 kw and operates at 825 F inlet steam temperature, with a pressure of 400 psig. Here greater use of alloy steels was made. Incidentally, it has created another record: for 13 long years it gave regular service without its having the high-pressure turbine opened for examination or repairs. This unit is lovingly referred to as "Big Ben."

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[4] Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrules Stock (B 111 - 51), 1952 Book of ASTM Standards, Part 2, p. 317.

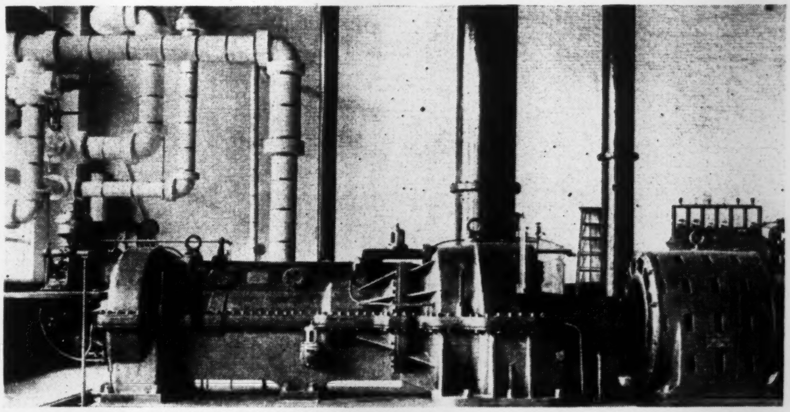

FIG. 11.—2000-kw Turbine-Generator—1900 to 1902.

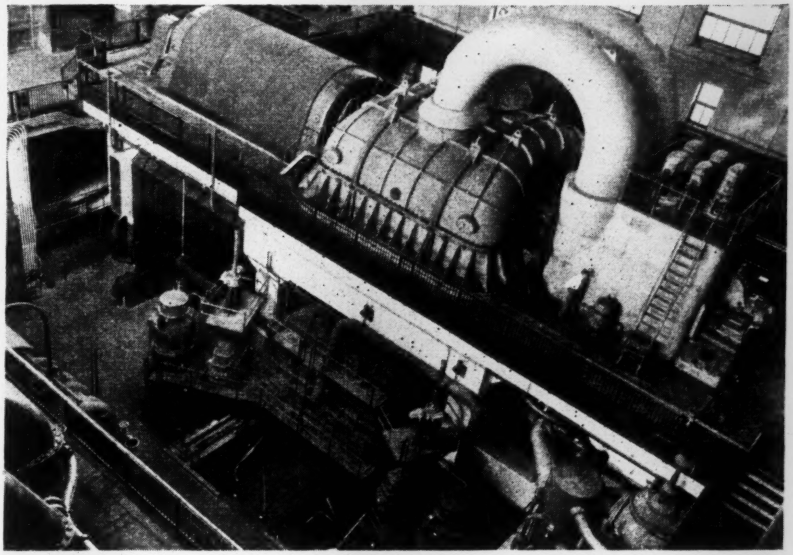

FIG. 12.—165,000-kw Turbine-Generator and Auxiliaries. Richmond Station, Philadelphia Electric Co.

As we step out onto the turbine floor at Sewaren (Fig. 13, Plate A), you will see before you four modern units, all operat-

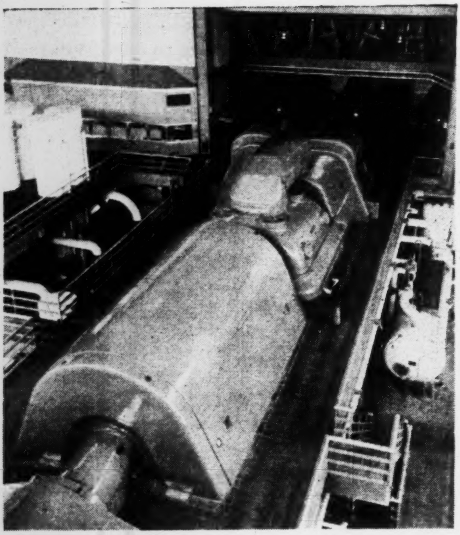

FIG. 14.—No. 1 Unit, 110,000 kw. Sewaren Generating Station.

ing at 3600 rpm, all on 1050 F steam; three are 110,000-kw units, one is of 125,000-kw capacity. Nos. 1 and 4 are Westinghouse-built units, and Nos. 2 and 3 are General Electric-built units.

Let us climb higher and get a better all-over view (Fig. 14) of No. 1, the generator in the foreground, then the low-pressure turbine, and the high-pressure turbine beyond.

I would not hurry you around Nos. 2 and 3; you would want to look them over carefully, too.

And then I would lead you to No. 4, which represents another extremely important stage in turbine development, the three-cylinder, reheat, triple exhaust, single shaft, 3600-rpm turbine. Figure 15 is a shop view of this unit in the maker's plant, with the covers removed. The high-pressure turbine is in the foreground, the intermediate or reheat turbine with one third of the low pressure in the middle, and the two-thirds low pressure beyond. I would have you note the forged rotors, the blading, the bolting, the cast steel cylinders, the fabricated low-pressure casing.

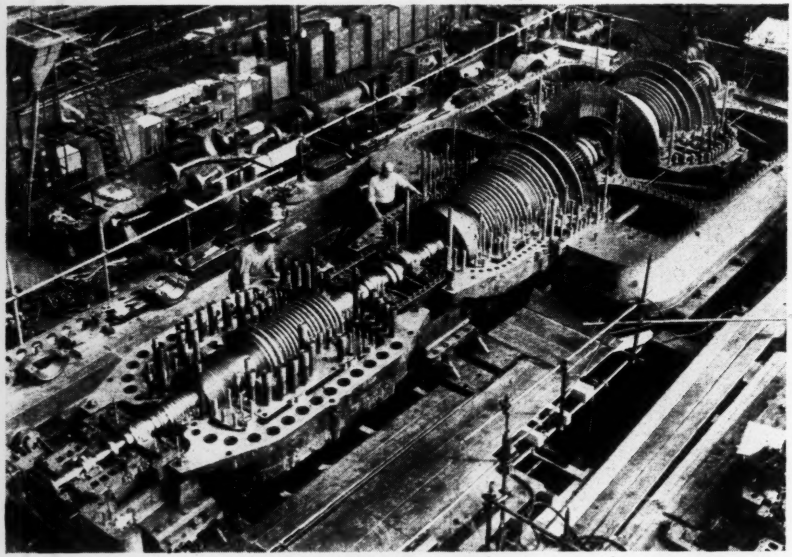

FIG. 15.—Shop Assembly View of Turbine for No. 4 Unit. Sewaren Generating Station.

The important position of this three-cylinder design in our over-all turbine development justifies our looking at it a little more closely. The cross-section drawing, Fig. 16 (Plate A), illustrates it well. Red denotes high-temperature steam, blue intermediate, green low-temperature. Steam enters at 1100 F, 1050 F, or 1000 F, as the case may be, into the high-pressure turbine. After passing through the blading of this portion, the steam is returned to the steam generator where it is reheated to 1050 F or 1000 F, as the case may be, when it is led to the so-called intermediate turbine. After expanding through this blading, the steam is divided. One third of it continues forward and passes through the blading of a single-flow, low-pressure portion, mounted on the end of the intermediate pressure rotor; whereas the other two thirds of the steam is carried over to a double-flow, low-pressure portion having a separate rotor and casing.

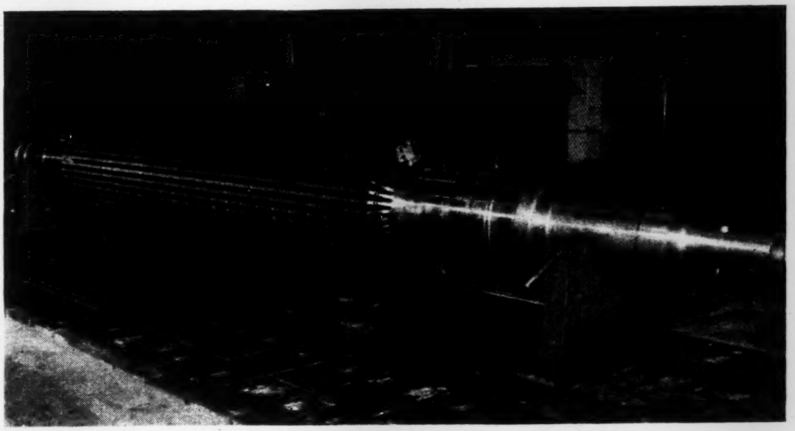

FIG. 17.—Typical 3600-rpm Generator Rotor.

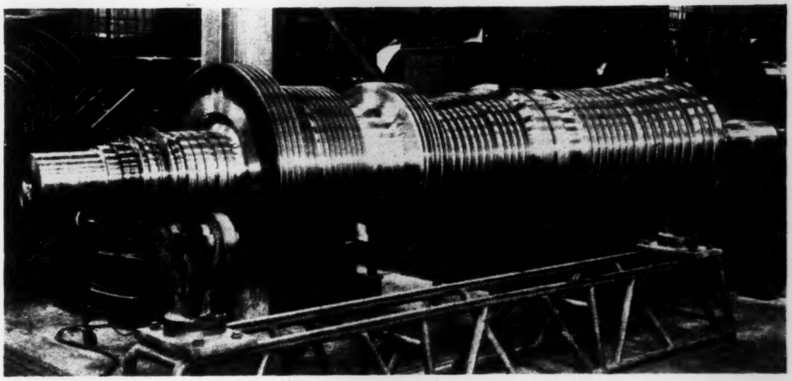

FIG. 18.—High-pressure, Reheat-type Turbine Rotor.

A FEW EXAMPLES OF METALS USED IN TURBINES AND GENERATORS

One can speak of many metallurgical developments and problems past, pres-

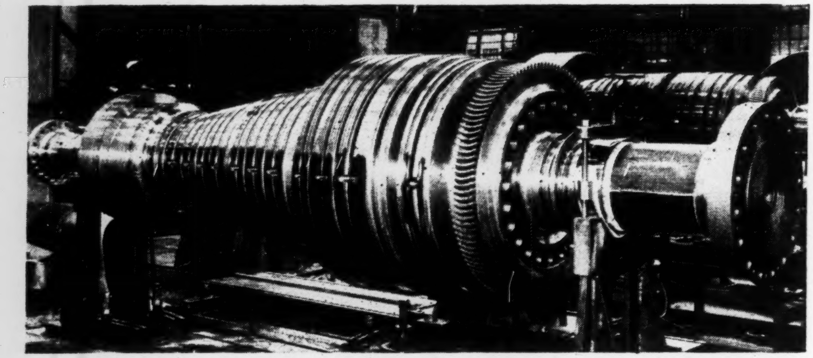

FIG. 19.—Intermediate-pressure, Low-pressure Turbine Rotor.

ent, and ahead. We will have time for just a few.

The very important position of large-single-piece forgings for both generator and turbine rotors is worthy of mention. Without such reliable forgings, the present developments could hardly have taken place.

Figure 17 shows a typical generator rotor. Rotors for this purpose have now reached a diameter of 43 in. and a main body length of 200 in., for new important 3600-rpm units.

Figures 18 and 19 are examples of finish-machined, turbine rotor forgings, ready for installation of the blading. Diameters are up to 55 in. for 3600-rpm units. Ni-Cr-Mo-V and Cr-Mo-V steels are used and, without resorting to liquid quenching, yield strengths of upwards to 100,000 psi are being secured. Strength and stability at high temperatures, with metal temperatures over 1000 F, are essential characteristics. Soundness naturally is a requirement, even with supersonic testing employed. Our Society has prepared specifications for such forgings (ASTM Specifications A 292 - 52 T and A 293 - 52 T).[5]

In the matter of blading, the development from comparatively thin blade sections in a brass material to the heavy blunt-edged sections of today in low-carbon 12 per cent chromium steel has

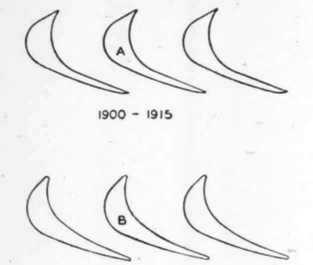

FIG. 20.—Evolution of Reaction Blade Sections.

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[5] Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 52 T) and Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts (A 293 - 52 T), 1952 Book of ASTM Standards, Part 1, pp. 746 and 751.

been an important matter (Fig. 20). The heavy section permits the formation of a rivet tenon of ample size to secure the shroud band to the outer end of the blade.[6]

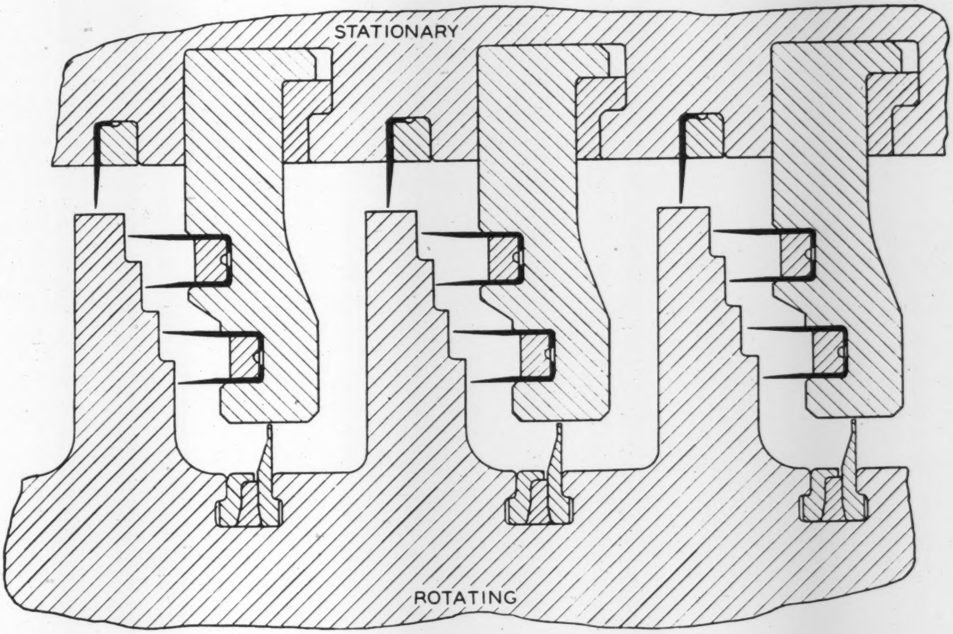

FIG. 21.—Arrangement of Seal Strips in Steam Turbine.

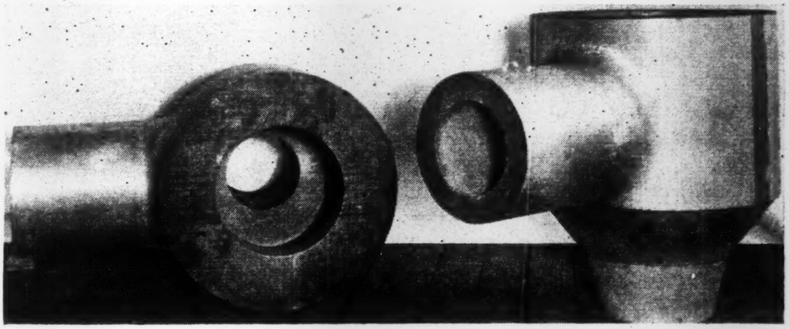

FIG. 22.—Throttle Valve Body Forgings.

Incidentally, the development of this low-carbon 12 per cent chromium steel for steam turbine blades has provided a reliable material that has had wide application in many fields. Its damping characteristics are noteworthy for a high-strength steel. Moreover, it has provided a base for the development of an entire family of interesting steels, as Mo, W, V, Co, Cb and other elements are added.

Modern turbines contain many little

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[6] Norman L. Mochel, "Wear in Steam Turbines," presented at the Summer Conference on Mechanical Wear, Massachusetts Institute of Technology, June, 1948, Mechanical Wear, Am. Soc. Metals, pp. 145–164 (1950).

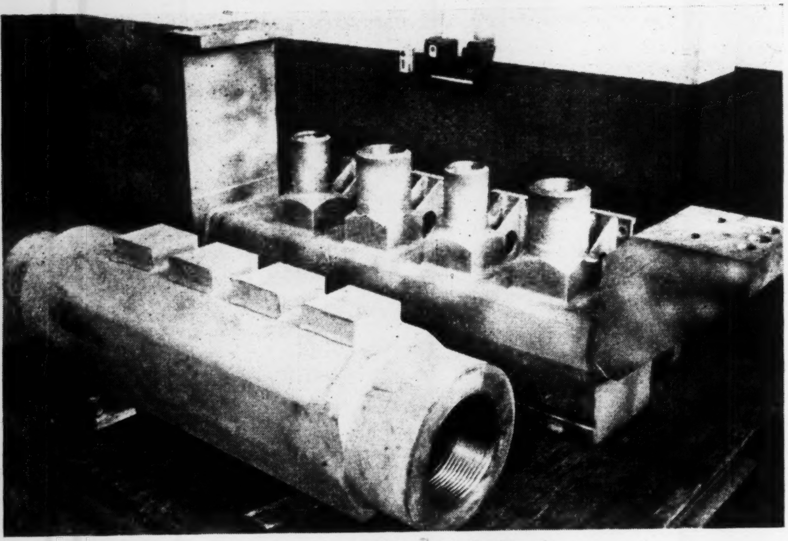

Fig. 23.—Steam Chest Body Forgings.

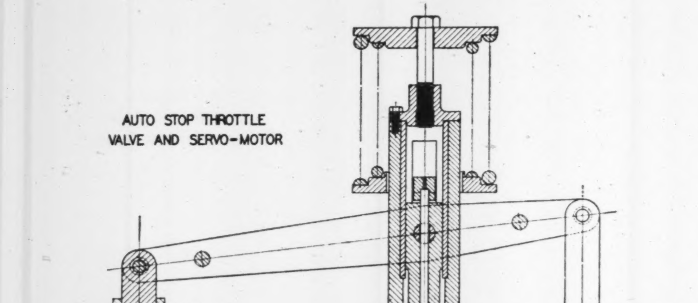
AUTO STOP THROTTLE
VALVE AND SERVO-MOTOR

Fig. 24.—Auto Stop Throttle Valve and Servo-Motor.

seal strips. Figure 21 is a typical case. The strips are sharpened to as little as 0.010 in. thick at the edges and operate with clearances as little as 0.020 in. The use of leaded nickel brass and of 12 per cent chromium - $\frac{1}{2}$ per cent molybdenum steel for such purposes has been discussed elsewhere.[6]

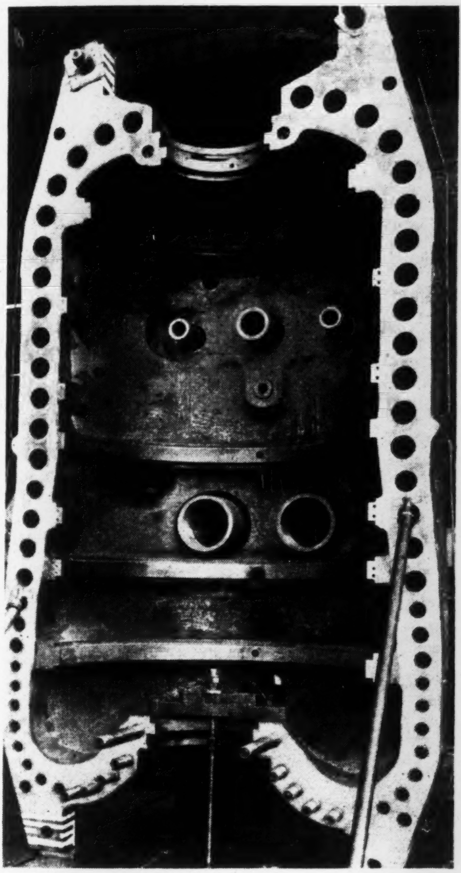

FIG. 25.—Turbine Cylinder Casting.

Forged throttle valve bodies (Fig. 22) and forged and weld-assembled steam chests (Fig. 23) in many steels including 18-8 Cb, $2\frac{1}{4}$Cr-1Mo, and Cr-Mo-V are interesting developments of recent years.

The selection of materials for valve stems and valve stem guide bushings for temperatures up to 1100 F involves questions of strength, expansion, wear, and freedom from galling or seizure.[6] Figure 24 illustrates a throttle valve for a modern steam turbine.

Cooperation between the larger steel foundries and the turbine builders has resulted in excellent turbine casing castings such as the one pictured in Fig. 25, produced in all types of Cr-Mo and Cr-Mo-V steels. Our Society is now preparing specifications for such castings (ASTM Specification A 356 - 52 T).[7]

Steam inlet piping (Fig. 26) in the many alloy steels, with many welded connections, has brought about many problems. One can at times find as many as 54 pipe welds in sizes 6 in. and larger at the front end of a modern turbine.

The front end of a steam turbine, where pressures are high and blades glow red, gets the lion's share of attention. But it is the exhaust row, the two end rows of Fig. 27, that fixes the amount of steam through the turbine, that determines the power rating. The pattern of steam turbine progress is represented by this quarter-century evolution of the last-row blades and the exhaust arrangement, which is summed up in Fig. 28. The triple exhaust feature earlier referred to is shown graphically here. The 25-in. blade is now before us. Note the tip speed of this blade at 1570 ft per sec. There will be longer blades than 25 in. wanted for newer 3600-rpm turbines. Whether these will be hollow or made of titanium in order to reduce the centrifugal loading, it is too early as yet to judge. Titanium blades have been forged.

The last row of blades for 1800-rpm turbines reached a length of 40 in. Along side in Fig. 29 is a 25-in. blade for the 3600-rpm machines. The little blade at

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[7] Tentative Specifications for Heavy-Walled Carbon and Low-Alloy Steel Castings for Steam Turbines (A 356 - 52 T), 1952 Book of ASTM Standards, Part 1, p. 966.

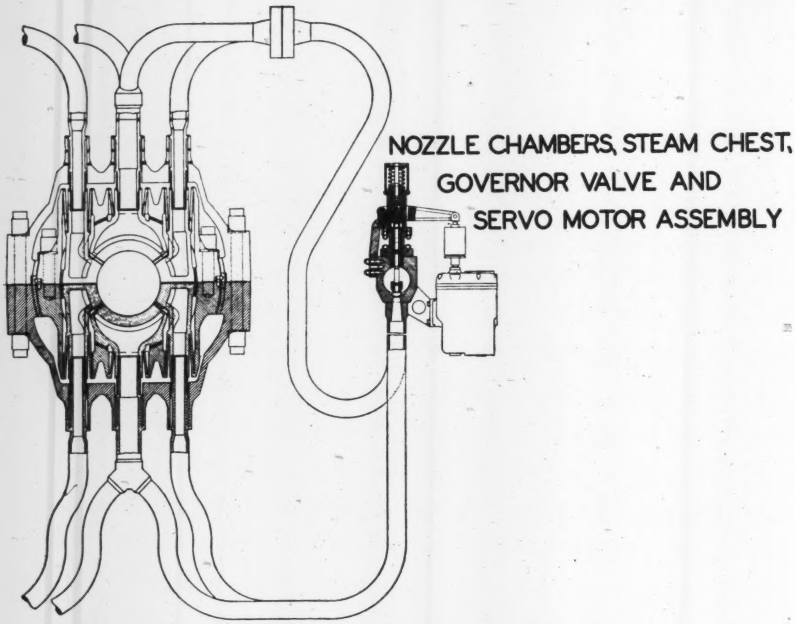
NOZZLE CHAMBERS, STEAM CHEST,
GOVERNOR VALVE AND
SERVO MOTOR ASSEMBLY

FIG. 26.—Steam Piping, Nozzle Chamber, and Steam Chest Arrangement.

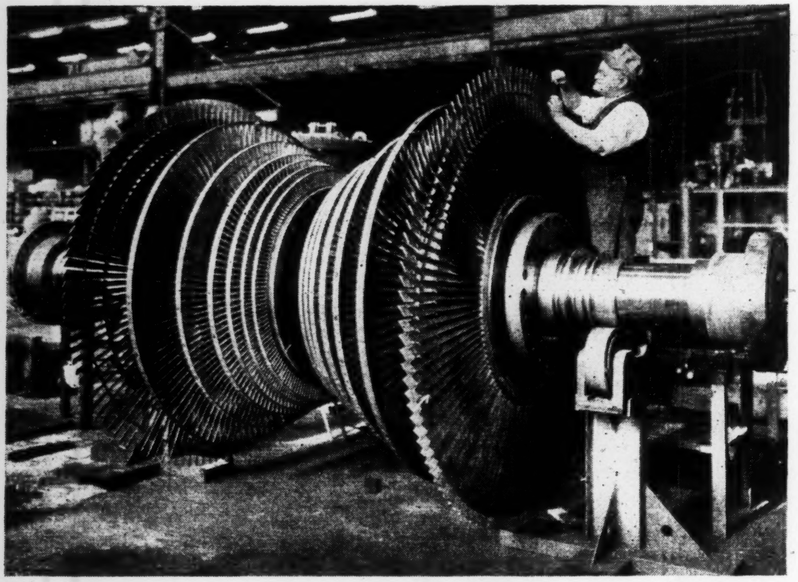

FIG. 27.—Low-pressure Bladed Turbine Rotor, 3600 rpm.

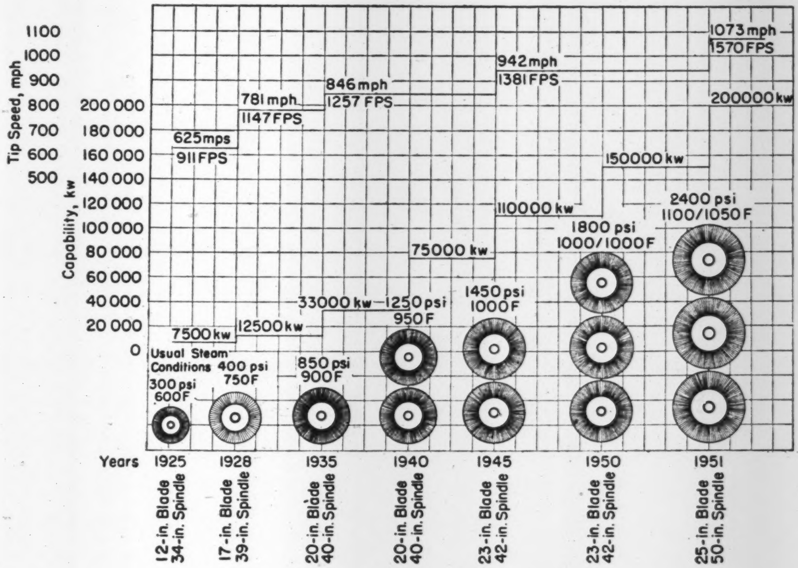

FIG. 28.—Progress in Turbine Exhaust End Blading.

the lower left is one that you would have found in the 2000-kw Hartford unit of 1902.

Now, before we leave the power plant, let us sit down in the lobby and see how far we have come, where we are, and where we appear to be going. We shall have time for just a quick glance at each.

Note how the advancement in materials, the use of feed-water heating, the employment of reheating, the use of higher temperatures and pressures, as the years have passed, have consistently improved the over-all station heat rate and the output of the coal pile (Fig. 30).

Figure 31 was prepared for a mid-century review in 1950. The 3600-rpm turbine had reached the value of 125,000 kw and 1050 F inlet steam temperature. D. W. R. Morgan[8] in 1950 courageously talked even then of capacities of 300,000 kw. Already we have turbines being built and more under design for 187,500 kw at 1100 F and 200,000 kw at 1000 F. Tur-

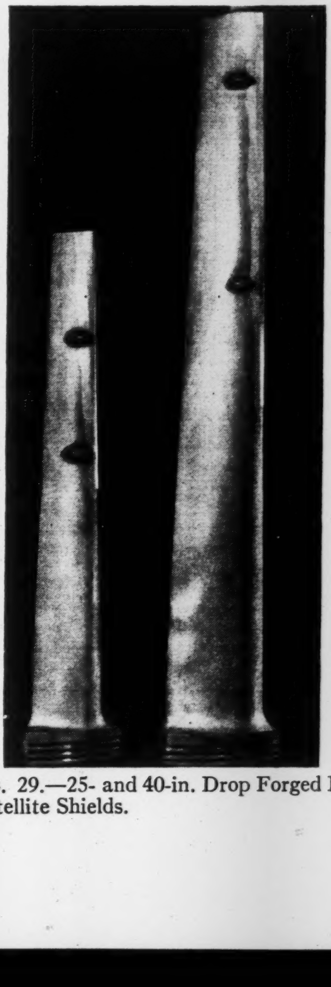

FIG. 29.—25- and 40-in. Drop Forged Blades with Stellite Shields.

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[8] D. W. R. Morgan, "Central Station Steam-Power Generation," *The Westinghouse Engineer*, Vol. 10, No. 1, January, 1950, pp. 7-17.

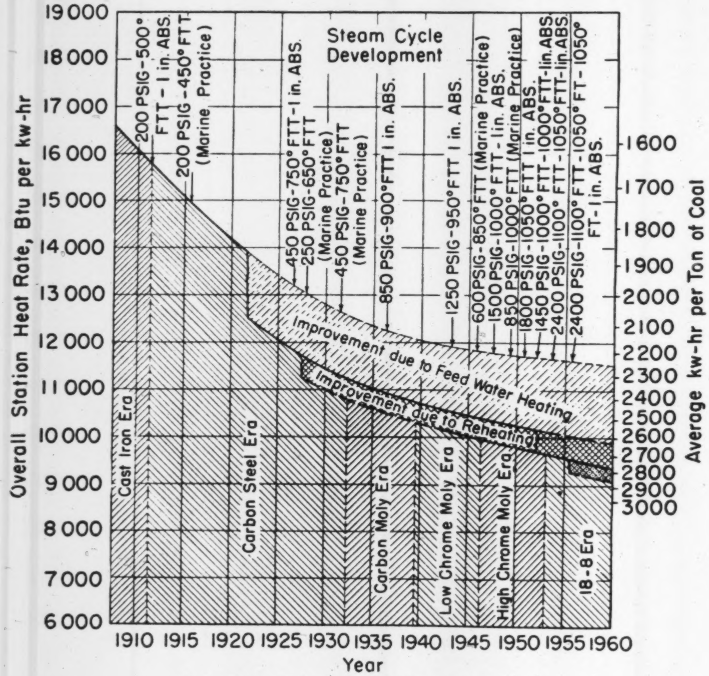

FIG. 30.—Steam Cycle Development.

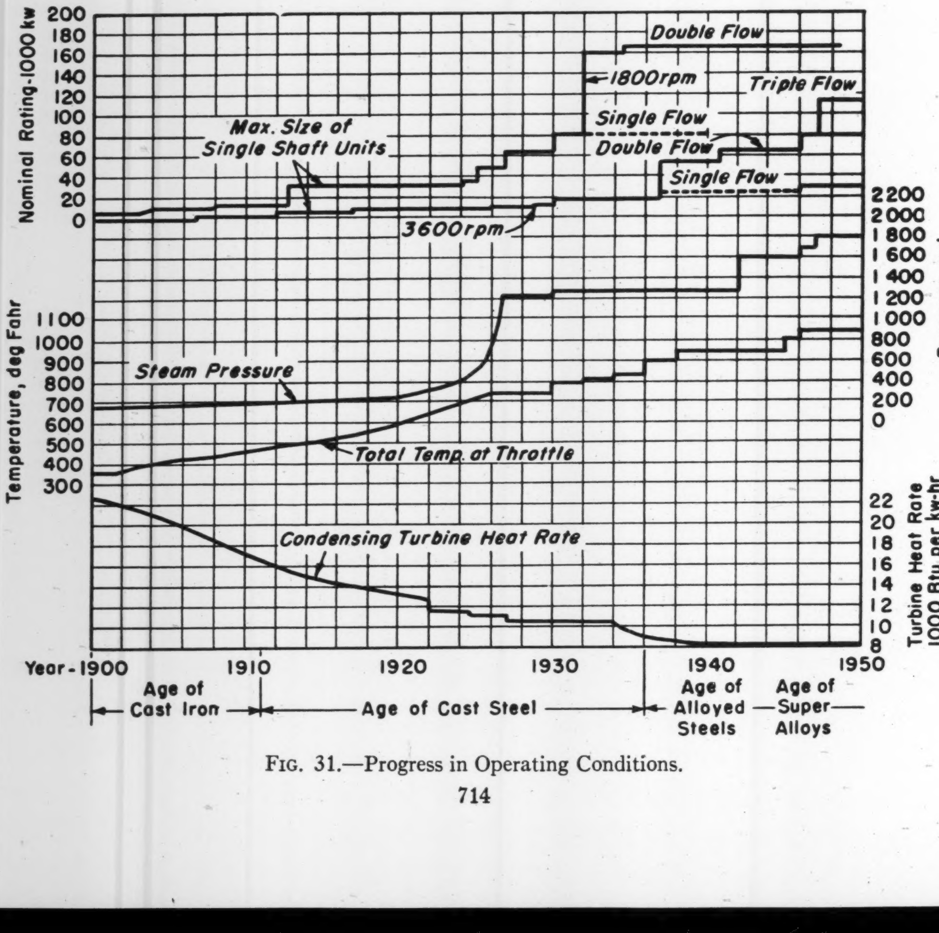

FIG. 31.—Progress in Operating Conditions.

bines with capacities of 250,000 kw are in negotiation[9] (Fig. 32).

In the last 50 or so years, we have made progress along lines that affect material considerations in several interesting ways. Note in Fig. 33 that in the matter of temperature increase, there has been a progress of more or less 12 F per year. Two turbine builders' progress has been pictured here. In the matter of weight, Fig. 34 illustrates the progress along these lines. A new unit to go into service in 1954 will require but 18 lb of structural steel per kw of capacity.

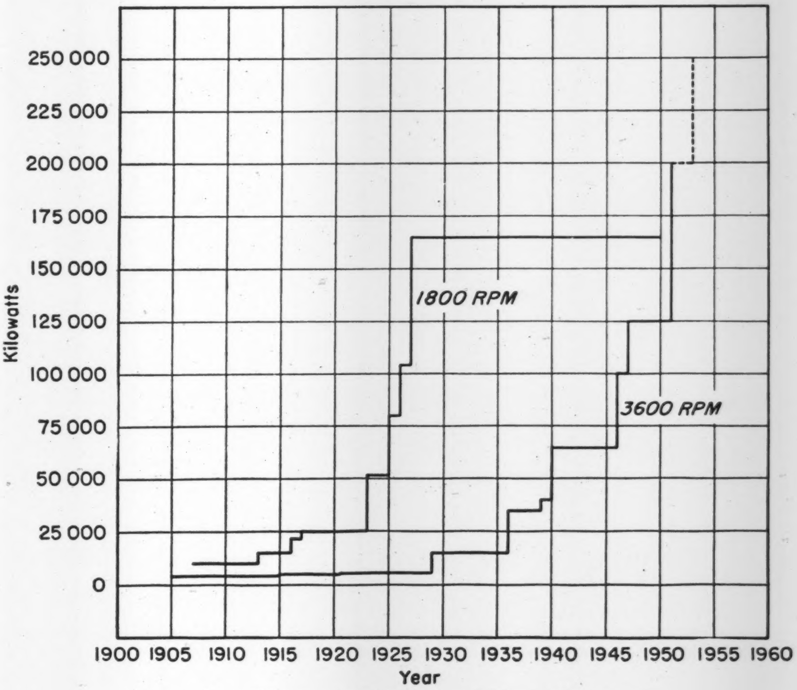

FIG. 32.—Progress in Capacities of Steam Turbines.

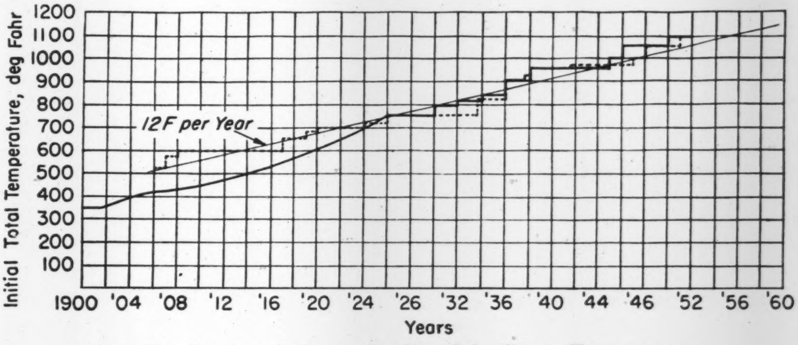

FIG. 33.—Progress in Steam Turbine Inlet Steam Temperatures.

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[9] Orders have since been placed for 250,000-kw units and these are now in the design stage.

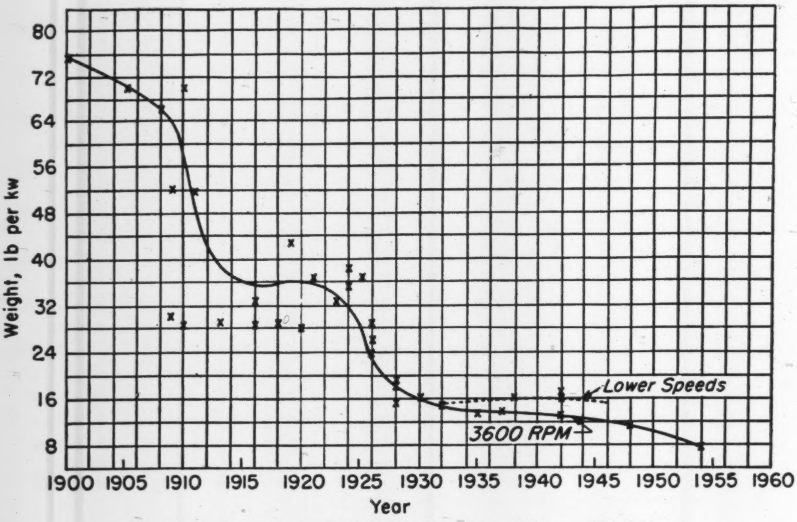

FIG. 34.—Progress in Weight Reduction of Steam Turbines.

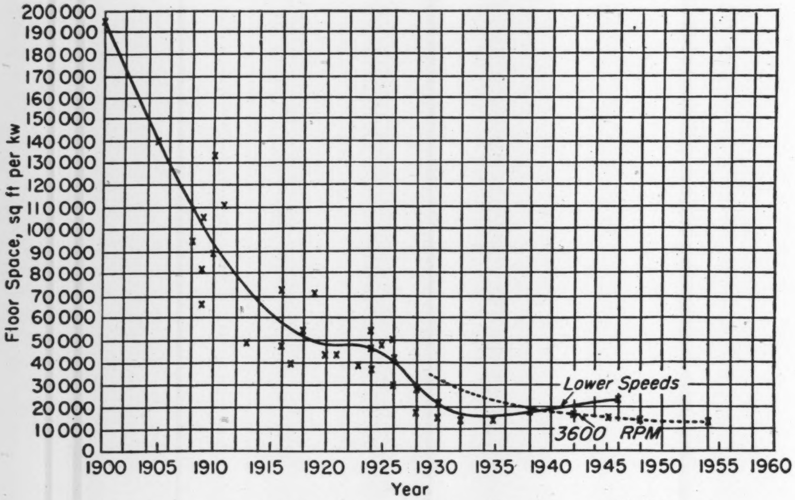

FIG. 35.—Progress in Floor Space Reduction of Steam Turbines.

whereas new construction in 1945 required 40 lb per kw. There follows also a great reduction in floor space (Fig. 35).

And now, what is ahead? Ayers and Scarlott have shown the domestic consumption of electricity over the years (Table I).[10] They suggest a tremendous increase in the amount that our children will use. It has been estimated that our

TABLE I.—UNITED STATES DOMESTIC CONSUMPTION OF ELECTRICITY.

Kilowatt-hours per annum per householder.

Year	Amount
1917	268
1927	446
1937	800
1950	1 825
Potential	10 000

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[10] Eugene Ayres and Charles A. Scarlott, "Energy Sources—The Wealth of the World," McGraw-Hill Book Co., Inc., New York, N. Y. (1952).

156,000,000 population of 1952 will be 175,000,000 by 1961. Our needs are growing. Our defense production is growing. Atomic development considerations will need a great deal of power.

I have tried to put together in Fig. 36 the record of U. S. generating capacity from 1920 to 1952 and several predictions that have been made for the years ahead. The solid line 1951 to 1961 is a straight-line presentation of the "Electrical World" estimates.[11] The dotted line 1952 to 1965 includes the estimates of a private study. The highest estimates noted are for 1970, 1975, and 1980. There are some who feel that the 1980 value should be more like 250,000,000 kw.[10]

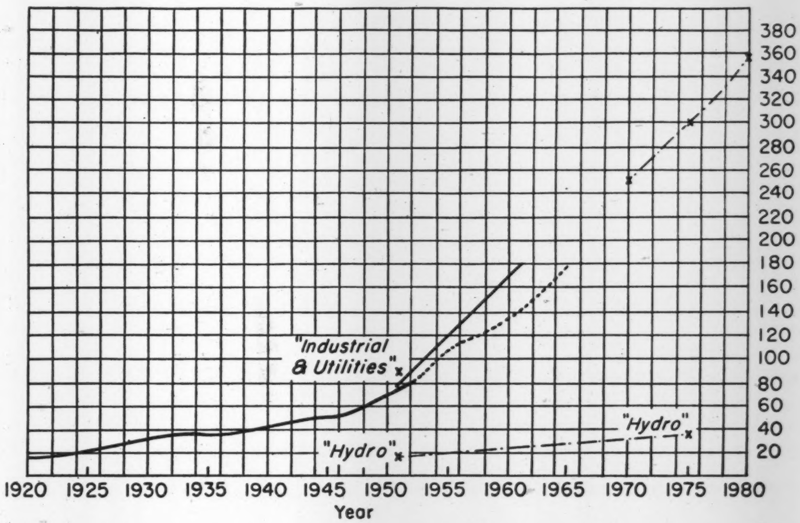

FIG. 36.—U. S. Generating Capacity, Millions of Kilowatts.

The estimate as regards power from hydraulic stations is open to question. Some feel that there is a maximum potential of 50,000,000 kw from this source and that this level may be reached in 1980.[10] Government policy, availability of suitable sites, and transmission problems all make this a difficult matter to judge.

Figure 37 attempts to show probable output in the years ahead. The solid line 1950 to 1961 are the estimates of "Electrical World." The 1965 to 2000 values are those suggested by Mr. Nevin E. Funk, formerly Executive Vice President of the Philadelphia Electric Co. Of course, estimates such as these can be made only by courageous people who believe in our country and its future.

The Westinghouse Co. has now broken ground for a new $6,000,000 laboratory at South Philadelphia for steam and gas turbine development (Fig. 38). Components up to 15000-kw capacity may be tested here. Steam up to 150,000 lb per hour and temperatures from 800 to 1100 F will be available. Also in the Philadelphia area, the General Electric Co. has opened a new switchgear laboratory.

We should mention the gas turbine field. It has been suggested that the development in this field for the next five years will be divided as follows:

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[11] "Ten Year Forecast for the Electrical Industry," *Electrical World*, Vol. 137, No. 20, May 19, 1952, pp. 136–137.

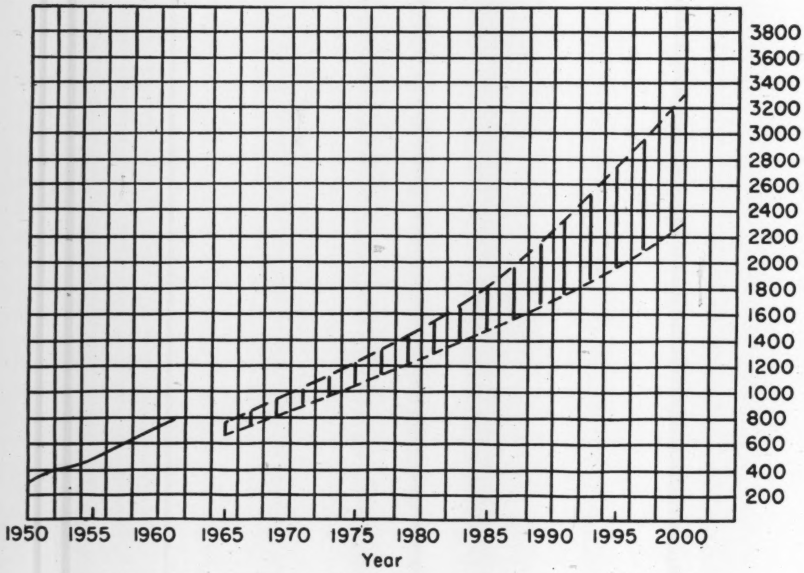

FIG. 37.—U. S. Generating Probable Output, Billions of Kilowatt-hours.

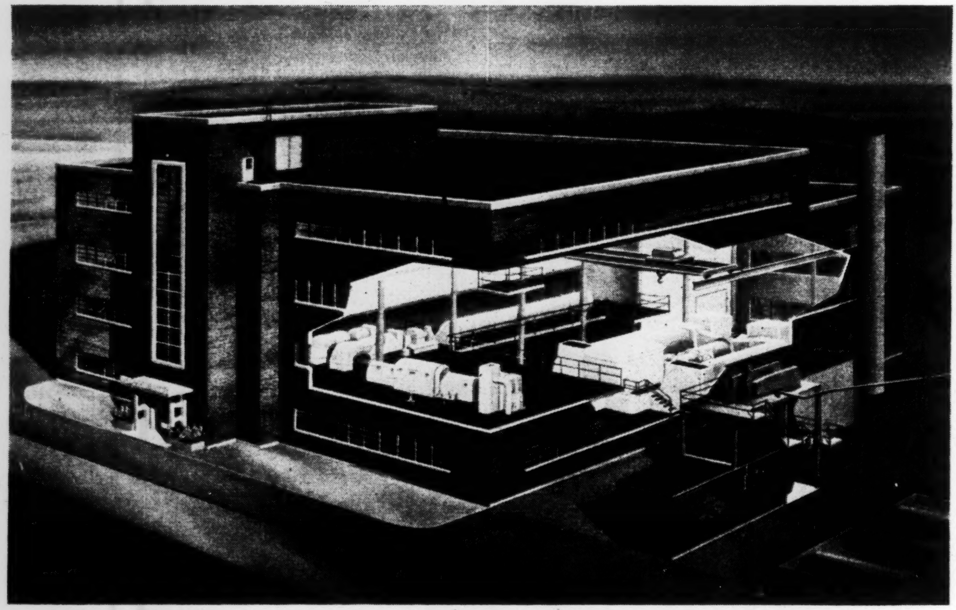

FIG. 38.—New Steam Division Engineering Development Laboratory.

For the petroleum and gas industry	45 per cent
For the central station industry	35 per cent
For the industrial applications	15 per cent
For locomotives	5 per cent

Units up to 15,000 kw for central station application are being built. A 5000-hp gas turbine is pictured in Fig. 39.

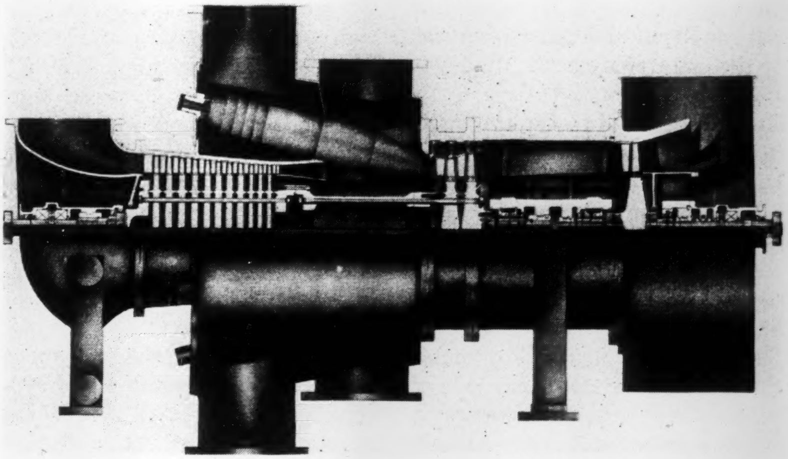

FIG. 39.—5000-hp Gas Turbine.

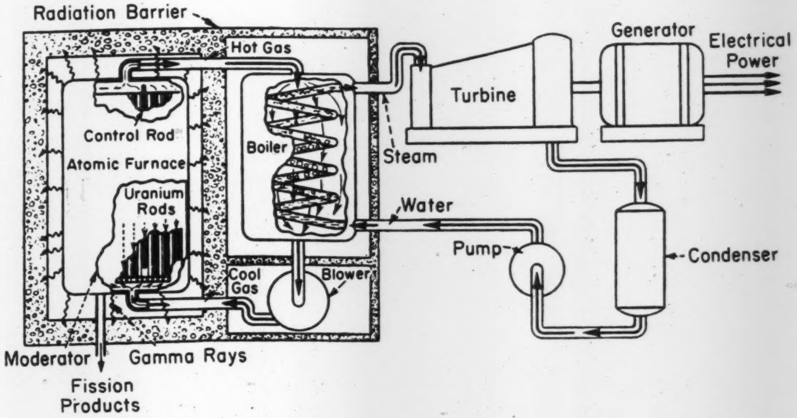
Radiation Barrier
Hot Gas
Control Rod
Atomic Furnace
Uranium Rods
Boiler
Steam
Water
Cool Gas
Blower
Moderator
Gamma Rays
Fission Products
Turbine
Generator
Electrical Power
Pump
Condenser

FIG. 40.—Atomic Power Turbine Generating System.

If I do not mention it, someone will wonder why I have not referred to the matter of atomic power. The development of useful power from atomic fission has been in progress in the U. S. since 1946. As of now a few hundred watts of electrical power have been generated at the Experimental Breeder Reactor developed by the Atomic Energy Commission and installed at their test site in Idaho, but no useful power of any consequence has come from the very considerable effort in the reactor development field. For this and other reasons it is clear that this is a long term project, but the general realization of this fact in itself represents progress.

Dr. L. R. Hafstad, Director, Division of Reactor Development, U. S. Atomic Energy Commission, has stated[12] that one of the two basic reasons why we should build reactors is power—central station power for the country's electric distribution system.

Enormous amounts of power are available from small amounts of fissionable material. There is the same amount of power in 1 lb of fissionable material as in 2,600,000 lb of coal. This comparison indicates the concentration of power being considered. The fact that the power is available is not the whole story, of course. The big question is: How much does it cost? If it costs more than power from coal or other fuels, the country is not going to gain in producing civilian electric power. From studies made by executives of electrical utilities and by a group of utilities companies and contractors now studying this problem for the AEC, the general conclusion can be reached that the economics of atomic power are now not attractive without selling the by-product, plutonium, to the government. But the development of reactors for power production is important for other reasons. These include the fact that atomic energy presents important military advantages in a mobile power plant. Concurrently it produces large amounts of power and fissionable material needed for military purposes. The technical know-how gained in present developments will make economically possible the building of plants primarily for the production of electrical power.

The basic cycle of operation of a nuclear reactor is shown in Fig. 40. From this we see the reactor as a heat source, the heat being transferred to a cooling fluid which is circulated through a heat exchanger by means of boilers or pumps. In the heat exchanger, water is heated to generate steam for use in driving a turbogenerator.

The technological problems in developing reactor materials, coolants, pumps, and control equipment for the primary cycle have been enormous. However, by concentrating a large percentage of the engineering manpower of the country on these problems, important strides have been made, and the industry is much more optimistic about the date when electrical power will be generated using atomic power as the heat source.

CONCLUSION

It would appear that the metal needs in the field of manufactured power will be great in the years ahead. There will be need for new development, for testing, for evaluation of our metals. There will be need for new ASTM standards and methods. We will not run out of work for this important application. And should the gas turbine or the atomic power developments make serious inroads on the steam turbine, the materials considerations are likely to increase the needs and problems from a metallurgical standpoint.

There will be many questions of supply, especially as our defense needs continue to increase in their demands. We must maintain a proper balance in the application of our available metals. This field of application must not suffer, because all else depends upon it.

One should mention the matter of copper. Although recent releases now show increased activities in the field of copper production, the demands for copper in the years ahead will be tremendous and will warrant our constant attention. The widespread activities on foot today to replace copper wherever possible with aluminum are of great significance. Such activities merit the cooperation of all.

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[12] Statement before the Third Annual Oak Ridge Summer Symposium on the Role of Engineering in Nuclear Energy Development, 1951.

Preachers usually announce their text in advance of their presentation. Mine appears at the head of this lecture but I mention it now in conclusion. The real test for greatness is service, whether it be man or material things.

Horace W. Gillett achieved greatness because of the manner in which he served his fellow man. This, to me, was his outstanding characteristic.

And in this first lecture in his memory, I have dealt with the application of metals to a field that has achieved greatness by reason of the service it renders to man.

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SUMMARY OF PROCEEDINGS OF THE CLEVELAND SPRING MEETING—SYMPOSIUM ON TESTING METAL POWDERS AND POWDER PRODUCTS

The papers in this Symposium on Testing Metal Powders and Powder Products were presented at the 1952 Spring Meeting of the American Society for Testing Materials in Cleveland, Ohio, March 5, 1952. This Symposium was sponsored by Committee B-9 on Metal Powder and Metal Powder Products.

Mr. F. V. Lenel, Powder Metallurgy Laboratory, Rensselaer Polytechnic Institute, Troy, N. Y., acted as Symposium Chairman and presided over the afternoon session, while Mr. W. A. Reich, Metallurgical Engineer, General Electric Co., Schenectady, N. Y., presided over the morning session.

The following papers were presented:

Introduction—F. V. Lenel
Test Methods and Devices for Sintered Iron Rotating Bands—John D. Dale
Quality Control of Metal Powder Gears—W. A. Hinkle
Porous Stainless Steel Compacts for Transpiration Cooling—F. V. Lenel and O. W. Reen
Methods of Testing Cemented Carbide Compositions—Alfred D. Stevens and John C. Redmond
Metal Powder Size Distribution with the Roller Air Analyzer—Paul S. Roller
Metal Powder Particle Size Determination—Richard Paul Seelig
Some Experiences in Specific Surface Measurement of Metal Powders by Low-Temperature Gas Adsorption—J. B. Haertlein and J. F. Sachse

These papers together with discussion are issued as ASTM Special Technical Publication No. 140, entitled "Symposium on Testing Metal Powders and Metal Powder Products."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON FATIGUE WITH EMPHASIS ON STATISTICAL APPROACH II

This Symposium, sponsored by Committee E-9 on Fatigue, was presented at the Eighth Session of the Fifty-fifth Annual Meeting of the American Society for Testing Materials held in New York, N. Y., on June 24, 1952. The papers emphasized the need for statistical procedures in the interpretation of fatigue data in order to indicate the important factor of variation. The following papers were presented:

Introduction—W. J. Youden
The Statistical Nature of the Fatigue Properties of SAE 4340 Steel Forgings—J. T. Ransom and R. F. Mehl
The Statistical Behavior of Fatigue Properties and the Influence of Metallurgical Factors—E. Epremian and R. F. Mehl
A Statistical Interpretation of the Effect of Understressing on Fatigue Strength—E. Epremian and R. F. Mehl
Fatigue Properties of Large Specimens with Related Size and Statistical Effects—Oscar J. Horger and Harry R. Neifert

These papers together with discussions have been issued as ASTM Special Technical Publication No. 137, entitled "Symposium on Fatigue with Emphasis on Statistical Approach II."

EFFECT OF PRIOR REPEATED STRESSING ON THE FATIGUE LIFE OF 75S-T ALUMINUM*

BY THOMAS J. DOLAN[1] AND HERBERT F. BROWN[1]

SYNOPSIS

The damage produced in 75S-T aluminum alloy by repeated loading at one stress amplitude was measured by the relative reduction of fatigue life when the specimen was retested at a second stress level. Specimens were prestressed at one of three selected stress levels and then tested to failure at a fourth or "test stress" level. The data reflect the unavoidable scatter inherent in fatigue life. By averaging the performance of a number of like specimens subjected to the same test conditions, the trends of the data indicated that when the prestress was higher than the test stress, the damage was greater than the prestress cycle-ratio; but when the prestress was lower than the test stress, the damage was less than the prestress cycle-ratio. For specimens subjected to a "coaxing" treatment, complete fracture of the specimens resulted after a stress history involving a relatively low cycle-ratio.

The conventional *S-N* diagrams derived from fatigue tests illustrate the behavior of individual specimens each of which is subjected to a stress history involving only a single (constant) stress amplitude. These data cannot rationally be used to predict the fatigue behavior (or the relative fatigue damage) in a member of a machine that is subjected to varying amplitudes of stress during normal service. Thus far, no accurate quantitative procedure has been devised for design of members subjected to repeated loading conditions involving variations in stress amplitude.

Repeated stressing is often thought of as developing a progressively increasing damage until fracture occurs. That is, it is sometimes inferred that the damage is cumulative or that it can be measured by the number of cycles of repeated stress. Several investigators have conducted experiments to determine the effects of previous stress cycles of different amplitude on the finite fatigue life of metals.

For example, Bennett (**1**)[2] studied the damage in alloy steel produced by repeated loading at one stress amplitude by measuring the relative reduction of fatigue life when the specimen was retested at a second stress level. His data indicated that the apparent rate of damage measured in this manner was dependent on the relative magnitude of the prestress as compared with the test stress at which the final fatigue life was measured. Some data (**2, 4**) of this nature are available for aluminum alloys, but the inherent statistical scatter of life in a fatigue test makes it difficult to draw

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill., and former Graduate Student, University of Illinois, Urbana, Ill., respectively.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 740.

definite conclusions about the extent of damage in a given specimen and its relation to the conventional data shown on an S-N curve. Miner (3) has suggested that the cumulative cycle-ratios ($\Sigma n/N$) at each stress level could be used directly as an index of the relative damage.[3] However other investigators (1, 2, 4) have found that by varying the sequence of applying the different magnitudes of stress, a wide range in value of the cumulative cycle-ratio for failure may be obtained.

It was the purpose of this investigation to study the damaging effects caused by prestressing 75S-T aluminum alloy as measured by the subsequent endurance life of the alloy at a single level of test stress. The relative damage was arbitrarily measured by comparing the increase or decrease in fatigue life at the test stress with the cycle-ratio employed in the previous stress history. Small rotating-beam specimens were studied to determine whether the behavior of this aluminum alloy was similar to that observed by Bennett for alloy steel and 24S-T alloy. A short series of experiments were also conducted to study the possible existence of a coaxing effect in 75S-T.

TABLE I.—MECHANICAL PROPERTIES OF THE 75S-T ALUMINUM ALLOY.

Ultimate strength, psi	83 680
Yield strength (0.2 per cent offset), psi	73 060
Elongation (2 in.), per cent	16
Reduction of area, per cent	31.6
Charpy impact, ft-lb	5.0
Brinnell hardness (500-kg load)	158

Due to the inherent scatter in fatigue data, a relatively large group of test specimens was employed to define the average life for each test condition. This was considered necessary to produce consistent trends and also to indicate the extent to which specimens selected at random might vary in their behavior.

TABLE II.—ENDURANCE LIVES AT CONSTANT STRESS AMPLITUDE FOR THE FOUR STRESS LEVELS USED IN THE INVESTIGATION.

Number of Cycles[a] to Failure			
30 000 psi Stress	35 000 psi Stress	40 000 psi Stress	45 000 psi Stress
433	558	97	63
2 223	668	98	119
2 427	819	105	130
3 010	877	117	131
4 079	1040	122	149
5 300	1120	129	168
5 606	1234	176	191
6 750	1353	202	194
6 857	1400	203	195
8 157	1545	230	196
8 458	2029	234	233
8 477	2086	261	244
9 583	2242	280	256
10 433	2359	300	268
10 648	2693	517	268
10 905	2823	566	374
10 991	3664	687	463
11 577		733	
12 074		1024	
13 919			
14 873			
15 124			
15 228			
15 386			
15 819			
15 839			
16 282			
17 525			
19 117			
19 698			
20 115			
20 303			
20 631			
20 725			
21 764			
22 402			
22 725			
22 919			
23 255			
23 509			
24 072			
24 247			
30 758			
31 559			
32 424			
35 750			
41 678			
42 558			
42 746			
44 979			
45 590			
46 561			
47 777			
52 184			
60 501			
73 506			
117 423			
Average, or mean life... 26 363	1677	320	214
Standard deviation, σ... 20 263	846	255	94

[a] Cycles to failure are given in thousands.

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[3] The symbols $\Sigma n/N$ represent the cumulative cycle-ratio where n is the number of cycles applied at a given stress, and N is the number of cycles required to produce failure at that stress as determined from the conventional S-N diagram.

MATERIAL AND METHOD OF TESTING

The 75S-T aluminum alloy was received in $\frac{7}{8}$ in. diameter bars and had average mechanical properties as shown in Table I. The bars were split longitudinally and small rotating beam specimens were machined from each half of the bar. The specimens were in the form of cylindrical bars $1\frac{3}{4}$ in. long by $\frac{1}{4}$ in. in diameter with the central portion gradually reduced to a minimum diameter of 0.150 in. by turning the surface contour to a radius of $\frac{3}{4}$ in. The specimens were given a standard finish (5) with final scratches produced by 00 polishing paper running longitudinally.

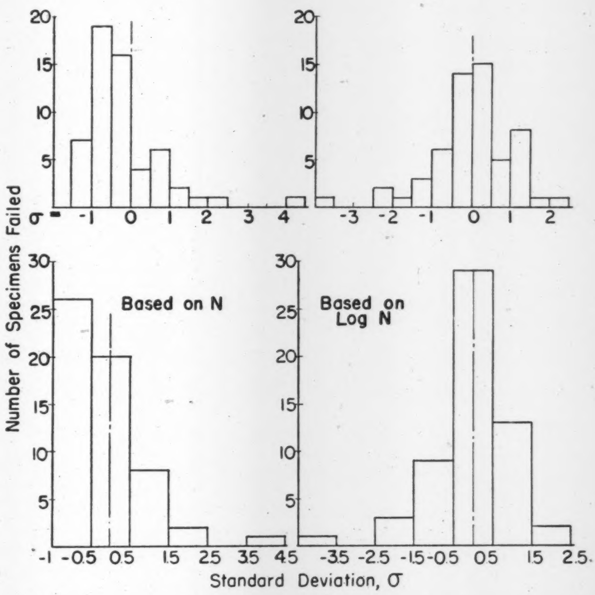

FIG. 1.—Distribution of Fatigue Life when Tested at 30,000 psi Stress.

Cell widths are equal to $\sigma/2$ in upper diagrams, and are equal to σ in lower diagrams. (Number of specimens = 57.)

Three small rotating cantilever-beam fatigue machines (which have previously been described (4)) were employed in the tests at a nominal speed of 8000 rpm. The stresses in the specimen were computed from the simple beam formula, $S = Mc/I$, in which S is the nominal stress amplitude at the extreme fiber of the test section.

Conventional fatigue tests at constant amplitude were conducted for four values of stress. From 17 to 57 specimens were tested at each of these stresses. The fatigue life for each of these specimens is listed in Table II together with the arithmetical mean life and standard deviation for each of the four stress levels considered. For the stress level of 30,000 psi these data are also presented graphically in a frequency distribution histogram in Fig. 1. These charts were plotted with a cell width equal to the standard deviation, σ, and with a cell width of $\sigma/2$ both in terms of N and log N. It will be observed that the distribution based on the number of cycles, N, is highly skewed, but becomes more nearly a normal distribution when based on log N. In either case the standard deviation is relatively large. The significance of these distributions will be discussed briefly in connection with results of the damage tests.

For the damage testing, each specimen was first prestressed for a predetermined number of cycles at one stress amplitude and was then run to failure at a second or test stress. The test stress was 35,000 psi in all cases, and the prestress levels were 45,000, 40,000 and 30,000 psi. In line with the work of previous investigators, the difference between the number of cycles to failure at the test stress and the mean fatigue life at the test stress was used as an index of the damage. The "fatigue damage" is arbitrarily expressed as the percentage reduction in life at the test stress due to the prestressing (that is, $\frac{N - N_0}{N} \times 100$, in which N is the mean life at the test stress, and N_0 is the observed life at the test stress after the prestressing). The number of like specimens subjected to each definite test sequence varied from about 5 to 24 in the different series.

TABLE III.—RESULTS OF "COAXING" TESTS.

Unit Stress, psi	Number of Cycles at Stress Level	Cycle Ratio[b]	$\Sigma n/N$
STRESS LEVEL INCREASED IN INCREMENTS OF 5000 PSI			
19 000	14 782 000	0	0.55
24 000	15 654 000	0.0157	
29 000	12 296 000[a]	0.534	
19 000	26 266 000	0	0.45
24 000	15 002 000	0.015	
29 000	10 168 000[a]	0.432	
STRESS LEVEL INCREASED IN INCREMENTS OF 2000 PSI			
19 000	9 454 000	0	0.08
21 000	9 430 000	0	
23 000	17 872 000	0	
25 000	8 657 000	0.0173	
27 000	5 466 000[a]	0.0605	
19 000	29 486 000	0	0.28
21 000	14 771 000	0	
23 000	15 690 000	0	
25 000	14 950 000	0.0299	
27 000	15 190 000	0.1687	
29 000	1 802 000[a]	0.0783	
19 000	15 642 000	0	0
21 000	1 113 000[a]	0	
19 000	15 994 000	0	0
21 000	14 717 000	0	
23 000	3 472 000[a]	0	

[a] Specimen fractured.

[b] Cycle ratios are shown as zero for stresses less than 24,000 psi which was the approximate fatigue strength for one billion cycles of stress.

A few experiments were conducted to determine whether a coaxing effect similar to that observed in steels could be produced in the 75S-T aluminum alloy by periodically increasing the stress amplitude after millions of cycles of stress. These coaxing tests were conducted by using increments of either 2000 or 5000 psi for increasing the stress level; from 18 million to 30 million cycles of stress were applied at each stress level. The values of the cumulative cycle ratio $\Sigma n/N$ obtained for each specimen upon failure were computed and are listed in Table III.

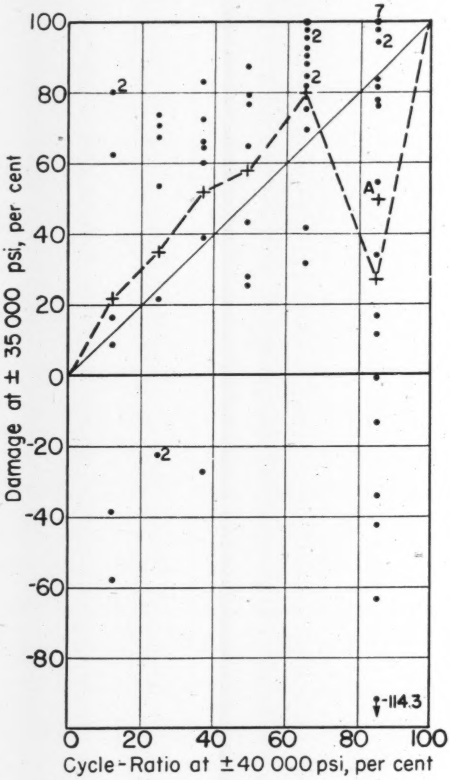

FIG. 2.—Damage at Test Stress Due to Prestressing at 40,000 psi.

DISCUSSION OF RESULTS

In Figs. 2 to 4 are shown graphical presentation of the results of the tests conducted to determine the damaging effect caused by prestressing for various portions of the life at the three prestress levels. The abscissas in these figures represent the cycle-ratio at the prestress and the ordinates represent the per cent damage at the test stress. It will be observed that if the plotted points fall below the 45 deg line drawn diagonally across the upper halves of these figures, the damage evident at the test stress was less than the cycle-ratio of the prestressing. If the damage is higher than the cycle-ratio, the plotted points fall above the 45 deg line. The plus marks connected together by broken lines represent the mean values of damage for all the tests at that cycle-ratio.

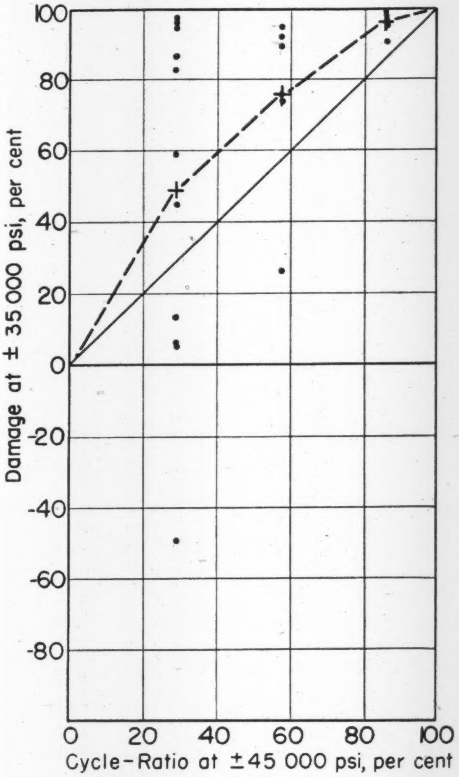

FIG. 3.—Damage at Test Stress Due to Prestressing at 45,000 psi.

The data in Fig. 2 show a considerable dispersion in results for the individual test specimens; some difficulty was also encountered in interpretation of the results because of the fact that some specimens failed during the prestressing operation. For example, at the 85 per cent cycle-ratio in Fig. 2, 24 specimens were prestressed at 40,000 psi; seven of these failed before the prestressing was completed. Even with this number of specimens, the low average-value of damage corresponding to the 85 per cent cycle-ratio did not conform consistently with the trend of the average values of damage at the lower cycle-ratios. In general, the average damage at all other cycle-

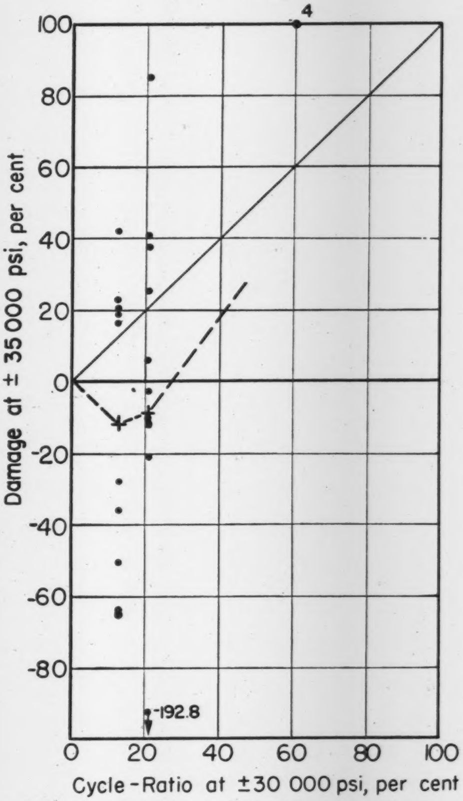

FIG. 4.—Damage at Test Stress Due to Prestressing at 30,000 psi.

ratios was somewhat higher than the cycle-ratio of the prestress, whereas the damage at the 85 per cent cycle-ratio was considerable less than the cycle-ratio. However, even this abrupt change at the higher cycle-ratio is consistent with data reported by Bennett and Baker (2) on 24S-T alloy.

It should be pointed out that the average or ordinate at the 85 per cent cycle-ratio was computed by omitting the seven specimens which failed during prestressing. If these seven specimens are each classified as having had 100 per cent damage and are included in the average, the ordinate is raised to the point denoted by A. This method of measuring damage does not take into account the fact that each of these seven failed far short of the average or expected original properties; hence from a statistical viewpoint they really should be regarded as having developed more than 100 per cent damage if included in the plot of specimens at 85 per cent cycle-ratio. If the specimen failed at 42 per cent cycle-ratio, this might conceivably be equivalent to 200 per cent damage when extrapolated to an 85 per cent cycle-ratio. Hence, perhaps a more realistic value for this average ordinate would be one nearly corresponding to the cycle-ratio, that is, 85 per cent.

The data in Fig. 3 show a somewhat more uniform trend for the damage produced by prestressing at a higher stress of 45,000 psi. In every case the mean per cent damage was greater than the prestress cycle-ratio. It is also interesting to note that the scatter of points was somewhat reduced as the cycle-ratio was increased.

In the original experimental program it was planned to prestress a number of specimens for various cycle-ratios at 30,000 psi, which was lower than the test stress; the results obtained are shown in Fig. 4. However, considerable difficulty was encountered because of failure of a large proportion of the specimens during the prestressing operation. This was undoubtedly due to the peculiar shape of the distribution function for finite life as indicated in Fig. 1. For example, an attempt was made to prestress four specimens to a cycle-ratio of 60 per cent of the mean life of 26,363,000 cycles at 30,000 psi. However, these specimens all failed before resisting the required 15,818,000 cycles. From Table II it can be observed that 24 of the 57 specimens tested at 30,000 psi had an endurance life of less than 15,818,000 cycles. That is, about 43 per cent of the specimens would naturally fail before completion of prestressing to a 60 per cent cycle-ratio. Due to this high probability of a large percentage of the specimens failing during prestressing, it was decided to discontinue any further testing at higher cycle-ratios than those shown in Fig. 4.

The average values of per cent damage at the test stress in Fig. 4 fell well below the 45 deg line indicating smaller damage than the prestress cycle-ratio. This trend was also consistent with the results of previous investigators; in general, reduced damage results when the prestress is lower than the test stress. In fact, the mean life at the two cycle-ratios indicated in Fig. 4 was actually longer than would have been obtained without prestressing; hence, the average per cent damage is shown as a negative value.

The Miner hypothesis (3) assumes a constant rate of accumulation of damage during repeated stressing; hence, the total damage should be proportional to the cycle-ratio. This would imply that the average results should fall on the 45 deg straight line in Figs. 2 to 4 (representing damage at the test stress equal to the prestress cycle-ratio). In general, however, when the prestress was higher than the test stress, the damage (as measured by the decrease in cycle-ratio) was greater than that predicted by the hypothesis. Conversely, when the prestress was lower than the test stress, the damage was much less than the prestress cycle-ratio.

Only a few experiments were conducted to investigate the effects of coaxing on the 75S-T alloy. These tests were all begun at 19,000 psi, which was well below the previously determined fatigue strength of 25,000 psi for 5 × 10^8 cycles.[4] The results of the coaxing tests shown in Table III indicate that the two specimens that were stepped-up in stress increments of 5000 psi, accumulated cycle-ratios of roughly $\frac{1}{2}$ before failure. The four specimens whose stress was increased in increments of 2000 psi, all failed at very low cumulative cycle ratios; thus it was obvious that no increase in life was obtained by the coaxing process. In fact, the low values of cumulative cycle-ratio indicate a rather pronounced decrease in life or a significant damaging effect. The largest values of $\Sigma\ n/N$ were obtained from the tests employing the larger stress increments. This was contrary to the general trends observed for steels in which coaxing is most effective when the stress increments are very small. This is again further evidence that no appreciable increase in life of the 75S-T resulted from the coaxing process. The tests, however, were too limited in scope to lead to general conclusions.

SUMMARY

Specimens of 75S-T alloy were subjected to reversed bending for various percentages of the mean fatigue life at one of three stress levels, and then tested to failure at a fourth or test-stress level to determine the relative reduction in fatigue life produced by the previous stressing.

The data reflect the unavoidable scatter inherent in fatigue tests. However, by averaging the performance of a number of like specimens, the trends of the results indicate that the proportionate damage was greater than the cycle-ratio of the prestressing when the magnitude of the prestress was greater than that of the test-stress. For a prestress lower than the test stress, the proportionate damage was less than the cycle-ratio.

The slopes of the average damage curves in Fig. 2 to 4 might be interpreted as meaning that for a prestress greater than the test stress, the rate of damage is initially high in the early cycles, but decreases as the prestressing proceeds toward failure. The results of a limited number of coaxing tests using two different increments for increasing the stress level indicated that no prolongation of life occurred; complete fracture of the specimens resulted after a stress history involving a relatively low cycle-ratio.

Due to the inherent statistical dispersion in life of fatigue test specimens, a cycle-ratio based on the mean life of a group of specimens does not represent the correct cycle-ratio for an individual specimen. Hence there is an unknown scatter in the true value of this cycle-ratio for each specimen subjected to a given prestressing sequence. This is one of the major reasons for the large scatter observed in the damage tests. Thus it seems evident that the prediction of the fatigue life of any given specimen that is subjected to a known random stress history becomes practically impossible. One can only predict the probability of a given life, based on statistical data obtained from a large number of like samples tested under the same conditions.

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[4] The *S-N* curve for the 75S-T alloy is shown in Fig. 12 of the author's earlier work (4).

Acknowledgment:

This investigation was conducted as a part of reasearch project NR-031-005 sponsored by the Office of Naval Research, United States Navy, in the Department of Theoretical and Applied Mechinics at the University of Illinois. Appreciation is expressed to the Metallurgy Branch, Office of Naval Research, for their continued interest in and support of this project.

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DISCUSSION

MR. J. A. BENNETT.[1]—I think that the difficulty which the authors experienced in getting so many premature failures, that is, failures before the desired cycle ratio had been run, would have been eliminated if they had used the median rather than the average fatigue life as a basis for the cycle ratio computation. For example, referring to Table II, it will be noted that 17 specimens, or 30 per cent of those tested at 30,000 psi, failed at less than 60 per cent of the median, as compared to the 43 per cent which failed at less than 60 per cent of the mean.

There is the other advantage, of course, that the determination of the median requires only the ability to count and does not involve the use of a calculating machine.

MR. R. L. TEMPLIN.[2]—It may be pointed out that the material under discussion is perhaps the one outstanding commercial alloy we have that shows a rather large variation in its fatigue properties, and I think it is fair to ascribe some of the difficulties encountered by the author to the choice of this material.

Mention was made that some work had been done on 24S-T alloy, as well as 75S-T alloy. In general, we have found that the fatigue properties of 24S-T come within definitely closer limits or scatter bands than those of the 75S-T material. Perhaps a brief explanation might be in order.

As you may know, the 75S-T represents one of our latest commercial high-strength aluminum alloys, and due to the pressure to supply it for military and other needs we have had to go through a number of growing pains in finding out the best manufacturing processes to use in producing the various commodities of that alloy. The result is that differences have been observed which may be reflections of these changes in fabrication processes. We hesitate to say that these variations are inherent in the alloy until we know more about the effects of these changes and variations that have been made during the early stages of the production of this material.

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[1] Chief, Mechanical Metallurgy, National Bureau of Standards, Washington, D. C.

[2] Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

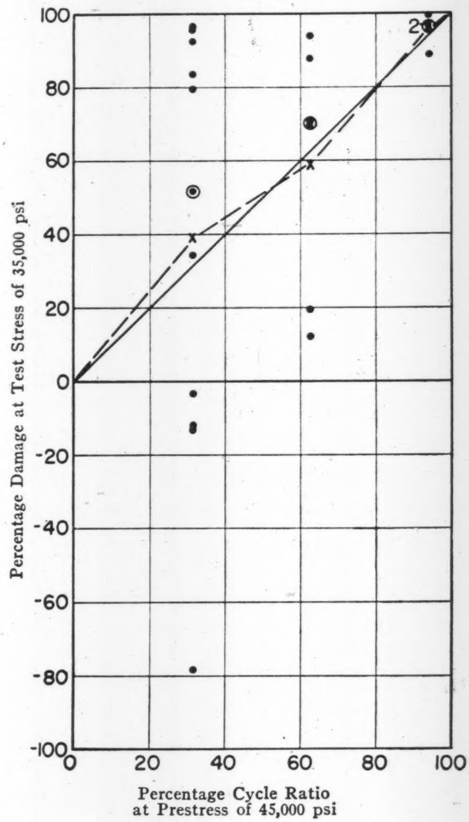

FIG. 5.—Damage at Test Stress Due to Prestressing at 45,000 psi—Based on median value of life.

I will not attempt to comment on some of the details of the accumulative damage and other points. I will leave that to some of my associates who are more closely connected with the details of the fatigue work than I happen to be at the moment.

MR. T. J. DOLAN (*author*).—I agree with Mr. Bennett that using the median value is probably a simpler procedure than using the mean value in analyzing data of this nature. Using this different criterion will shift the results somewhat in curves of the types shown in Figs. 2 to 4. In examining the distribution of fatigue life for specimens tested at 30,000 psi, one finds that three times as many specimens failed short of the mean life as compared with those lasting longer than the mean life of the group. Thus, a pronounced difference in interpretation results from picking the *median* rather than the *mean* is the criterion of nominal fatigue life.

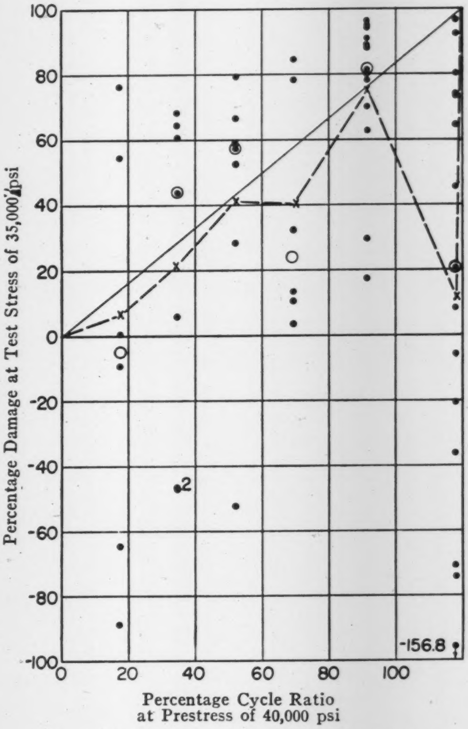

FIG. 6.—Damage at Test Stress Due to Prestressing at 40,000 psi—Based on median value of life.

To illustrate this difference, the data

in Figs. 2 to 4 have been replotted in the accompanying Figs. 5 to 7 by using the median values in Table II instead of the average as representing the nominal fatigue life. However the crosses and dashed lines in Figs. 5 to 7 have been drawn at the average value of the ordinates plotted from the test data. It will be observed that the trends are similar to those in Figs. 2 to 4, but the general result is a shift of the points to the right (that is, toward a higher cycle ratio of prestress). In effect, this makes the average ordinates conform more nearly to the condition in which the per cent of damage equals the per cent of cycle ratio of prestressing. However to be consistent, one should also utilize the *median* rather than the average ordinate in interpreting these results. The median values shown by large open circles show somewhat more scatter but follow trends more nearly consistent with those indicated by Figs. 2 to 4 that were based entirely on *mean* values. There are no physical reasons for deciding whether the mean or the median is the most appropriate criterion for judging fatigue life.

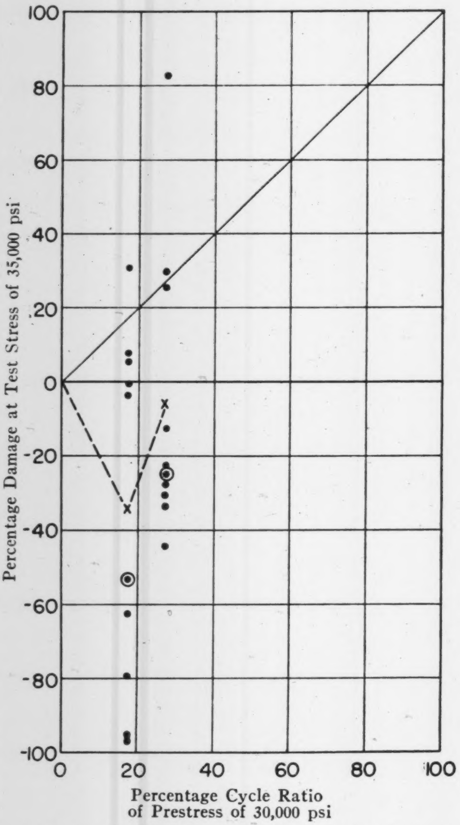

FIG. 7.—Damage at Test Stress Due to Prestressing at 30,000 psi—Based on median value of life.

With regard to the wide scatter in life obtained, Mr. Templin would undoubtedly agree also that some of the variation is due to the fact that we used very small specimens (only 0.150 in. in diameter). Each specimen thus indicates the quality of only a small individual region of the bar. The results are probably not representative of the average or integrated behavior of the larger volumes obtained in testing large specimens. I would expect less scatter if larger pieces were selected for the individual samples.

In testing small specimens, one must be extremely careful of the surface finish, the "out-of-roundness," and the measurements taken on the specimen. For example, at 0.150 in. diameter a deviation of 0.001 in. in measurement or out-of-roundness amounts to two-thirds of one per cent. The diameter is cubed in computing the stress which means the effective error becomes roughly 2 per cent. Thus extreme precaution in machining, polishing, and measuring is necessary to minimize the scatter. Though a carefully standardized procedure was followed in each of these operations, a small portion of the scatter may have resulted from minor variations in surface finish, shape of specimen, variation in wear of bearings of the testing machine, etc.

AN INVESTIGATION OF THE COAXING EFFECT IN FATIGUE OF METALS*

By G. M. SINCLAIR[1]

SYNOPSIS

The fatigue resistance of some metals may be improved by understressing followed by a process of gradually increasing the amplitude of the alternating stress in small increments, a procedure ordinarily called "coaxing." In the present paper a study is made of the effect of various coaxing procedures on the fatigue resistance of ingot iron, SAE 1045 and 2340 steels, 75S-T6 aluminum alloy and annealed 70-30 brass. The results of this study seem to indicate that the coaxing effect in fatigue is governed by a time-dependent localized strengthening through strain-aging and not by the ability of the metal to be strengthened by cold work.

It has been known for a number of years that the fatigue limit of many common engineering metals is not a fixed quantity but may be considerably affected by the previous cyclic stress history. One of the more interesting discoveries in this respect was the fact that the fatigue limit of some metals could be increased by more than 25 per cent by suitable understressing.[2] A still greater increase in the fatigue limit of the same metals was obtained when the understressing was followed by a "coaxing" process; that is, the fatigue limit was said to be "coaxed" to higher values by a procedure of gradually increasing the applied load in small increments and allowing a relatively large number of cycles of stress to occur after each new increase in load. Very great increases in finite fatigue life have also been obtained, Kommers (**1**)[3], for example, reported an increase in life of 23,000 per cent for ingot iron which was subjected to understressing plus coaxing.

The process of failure by fatigue seems to be initiated by crystal slip (**2**) in the metal. Those factors which tend to prevent or to inhibit slip might therefore be expected to increase fatigue strength. In the past the increase in fatigue strength which sometimes resulted from understressing plus coaxing has been attributed to a beneficial "cold-working" of the metal at the initially small stress amplitudes. There is some evidence that this supposition is incorrect and that local strain-aging of the metal rather than cold-working is probably responsible for the "coaxing" phenomenon. A careful survey of the literature on understressing disclosed that the metals which exhibited an increase in fatigue strength too great to be attributable to chance, were invariably ferrous metals (**1**, **3**, **4**, **5**, **6**).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Metallurgical and Ceramic Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

[2] Repeated stressing at or below the fatigue limit of the virgin metal.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 751.

Further studies of the effect of rest periods on finite fatigue life indicate that long periods of rest at room temperature or shorter periods of rest at mildly elevated temperatures (200 to 400 F) will greatly extend the fatigue life of some annealed steels but have no beneficial effect on hardened steel or non-ferrous metals (**7, 8, 9, 10**).

TABLE I.—CHEMICAL COMPOSITION AND CONDITION OF MATERIALS AS RECEIVED.

Material	Composition, per cent	Condition as received
Ingot iron........	C 0.012, Mn 0.017, P 0.005, S 0.025, Fe remainder	⅝ in. diameter rod, hot-rolled
SAE 1045 steel....	C 0.44, Mn 0.75, P 0.014, S 0.021, Si 0.21, Fe remainder	⅞ in. diameter rod, hot-rolled
SAE 2340 steel....	C 0.40, Mn 0.74, P 0.019, S 0.020, Si 0.28, Ni 3.48, Fe remainder	⅞ in. diameter rod, hot-rolled
75S-T6 aluminum..	Zn 5.6, Mg 2.5, Cu 1.6, Cr 0.3, Al remainder	⅞ in. diameter extruded rod, solution heat treated and artificially aged
70-30 Brass.......	Zn 30.21, Pb 0.07, Fe 0.01, Cu remainder	¾ in. diameter rod, 20 per cent cold-drawn

TABLE II.—HEAT TREATMENT AND MACHINING OF SPECIMENS.

Material	Heat Treatment, deg Fahr	Machining
Ingot iron (A Specimen)...............	1400—1 hr	Machined after heat treatment
Ingot iron (B Specimen)...............	1400—1 hr, water quenched	Machined before heat treatment
SAE 1045 steel.......	1500—1 hr, Normalized	Machined before heat treatment
SAE 2340 steel.......	1500—1 hr, Oil quenched tempered 900 —1 hr	Machined before heat treatment
75S-T6 aluminum.....	As received	Machined as received
70-30 brass...........	Annealed 900 F—4 hr	Machined before heat treatment

These facts suggested that the mechanism by which the fatigue strength of some metals may be coaxed to greater values is related to strengthening of the localized areas which yield under the initial cycles of stress, by a strain-aging process which occurs during subsequent cycles of stressing. Accordingly, one might expect that only those metals having a matrix susceptible to strain-aging will exhibit the coaxing effect.

OBJECT AND SCOPE

In order to test this hypothesis, five common engineering metals were selected and subjected to coaxing type fatigue tests. The first three—ingot iron, SAE 1045, and SAE 2340 steels—had a matrix of ferrite which was susceptible to strain-aging. The other materials were an annealed 70-30 brass which was capable of being strengthened by cold working but not by strain-aging, and 75S-T6 aluminum alloy which had a smaller capacity for being strengthened by cold work and none for further aging. The chemical analysis and original form of these metals is given in Table I.

Rotating-beam fatigue specimens were machined to the dimensions shown in Fig. 1 and polished mechanically using successively finer grades of emery paper. The final polish was given with a 00 grade of emery and was done in such a manner as to leave the scratches parallel to the axis of the specimen. Details of the heat treatments and mechanical processing of the specimens are presented in Table II.

METHOD OF TESTING

The tests were conducted in R. R. Moore type rotating bending fatigue machines at a speed of approximately 1200 rpm. Nominal stresses at the minimum section of the specimen were computed by means of the ordinary flexure formula:

$$S = Mc/I$$

where:

S = the stress at the outer fiber,
M = the bending moment applied, and
I/c = the section modulus at the critical section.

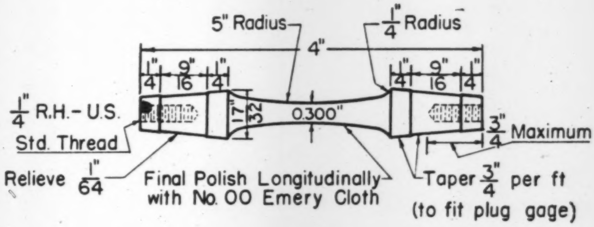

5" Radius
1/4" Radius
4"
1/4" 9/16" 1/4"
1/4" 9/16" 1/4"
1/4" R.H.-U.S. Std. Thread
17/32"
0.300"
3/4" Maximum
Relieve 1/64"
Final Polish Longitudinally with No. 00 Emery Cloth
Taper 3/4" per ft (to fit plug gage)

FIG. 1.—Details of Fatigue Specimen.

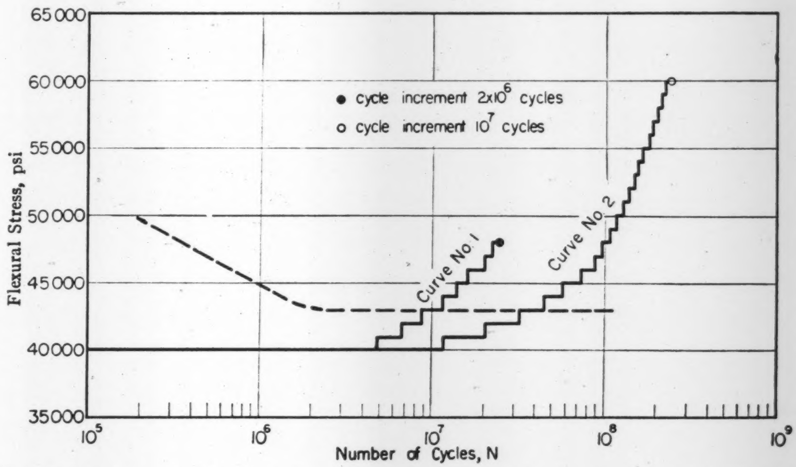


FIG. 2.—Influence of Cycle Increment on Coaxing Failure Stress of SAE 1045 Steel.

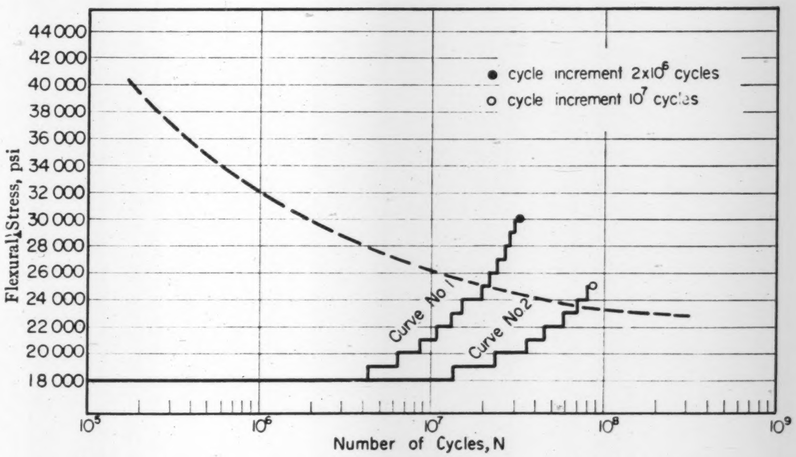


FIG. 3.—Influence of Cycle Increment on Coaxing Failure Stress of 75S-T6 Aluminum Alloy.

The experimental procedure consisted first of determining an *S-N* curve for each material in the usual manner (11) and then of finding the stress at fracture which was obtained for various conditions of coaxing. The effect of coaxing on each metal was determined for the following conditions: (1) increasing the coaxing stress using uniform increments of 500, 1000, 2000, and 3000 psi, respectively (2) increasing the number of cycles applied at each new stress from approximately two million to ten million. All tests were conducted at room temperature.

TABLE III.—SUMMARY OF TEST DATA, GROUP I.

Material		Ingot Iron B, unaged		SAE 1045 Steel		SAE 2340 Steel		Ingot Iron A, aged		75S-T6 Aluminum Alloy		70-30 Brass	
STATIC TENSION PROPERTIES													
Ultimate strength, psi		47 400		97 300		155 300				78 000		53 200	
Yield strength, 0.2 per cent offset		28 500		59 800		147 500				69 600		21 000	
Elongation, per cent in 2 in.		31.0		27.8		19.2				14.7		54.0	
Reduction of area, per cent		69.4		47.5		60.2				32.3		75.7	
FATIGUE PROPERTIES													
Fatigue strength at 10^8 cycles		24 000		44 000		85 000		37 000		23 000		17 000	
Initial coaxing stress		20 000		40 000		70 000		30 000		18 000		12 000	
EFFECT OF COAXING PROCEDURE ON FAILURE STRESS[a]													
Cycle Increment		2×10^6	10^7	2×10^6	10^7	2×10^6	10^7	2×10^6	10^7	2×10^6	10^7	2×10^6	10^7
Stress increment, psi	500	32 500		53 500				41 000		27 000		21 000	
	1000	34 500[b]	40 000	48 000	60 000	98 000	97 000	41 000	40 000	30 000	25 000	23 000	19 410
	2000	28 000	38 000	46 000	54 000	95 000	97 000	42 000	40 000	30 000	26 000	22 000	20 000
	3000	26 000	35 000	46 000	49 000	93 000	96 000	42 000	42 000	33 000	27 000	24 000	21 000

[a] Values listed in the table are those of the coaxing failure-stress.
[b] Initial coaxing stress 19,500 psi.

RESULTS OF TESTS AND DISCUSSION

Figure 2 presents two typical examples of the effect of coaxing procedures on the fatigue behavior of SAE 1045 steel. This material exhibited a relatively strong coaxing effect. The ordinary *S-N* diagram which was obtained by testing specimens to failure at a single stress level is represented by the broken line. The load and cycle changes which were made during the coaxing procedure are indicated by the solid lines. The results of two variations in coaxing procedure were shown in this diagram to help illustrate three terms which will be used throughout the remainder of this report. The number of cycles which were applied at one stress level before the stress was raised to a higher value during the coaxing process will be referred to as the cycle increment. The uniform step-like increase in stress which was applied during coaxing will be referred to as the stress increment. The stress at which failure occurred after a number of these coaxing steps were applied was called the coaxing failure-stress or for brevity, simply the failure stress.

In Fig. 2 the stress increment which was used in obtaining the two coaxing curves amounted to 1000 psi. Curve No. 1 resulted when a cycle increment having a value of approximately two million was used while curve No. 2 was obtained when the cycle increment was increased to approximately ten million. It should be noted here that the machines used in performing the coaxing tests required approximately one day to apply a cycle increment of two million and five days to apply a cycle increment of ten million. It may be observed in Fig. 2 that increasing the cycle increment has resulted in a higher coaxing failure-stress. This was observed to be generally true of the materials which had a matrix capable of being strengthened by strain-aging. That is, increasing the number of cycles applied at each stress level during the coaxing process resulted in an increase in the failure-stress.

The results obtained by applying these same coaxing procedures to specimens of 75S-T6 aluminum alloy are illustrated in Fig. 3. It may be seen that the reaction of this material to the coaxing procedure was quite different from that of the 1045 steel. Increasing the cycle increment for the aluminum specimens resulted in a reduction of the failure stress. This behavior was observed to be characteristic of the second group of materials which were examined; namely, those materials in which little or no strengthening due to strain-aging could be expected.

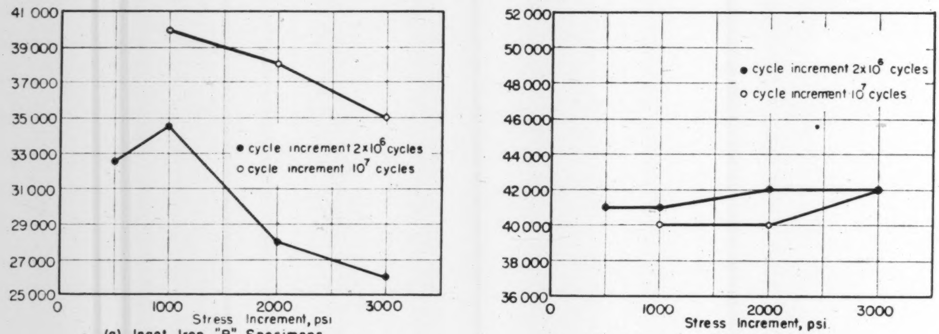
In the present paper an increase in the coaxing failure stress caused by increasing the cycle increment or by decreasing the stress increment has been interpreted as indicating that the fatigue resistance of the material may be improved by coaxing procedures.

In Table III the results of the entire coaxing study have been tabulated. The first section of Table III lists the static tensile properties that were obtained from standard test specimens of each material. The second section of the table records data obtained from the ordinary fatigue tests and from the various coaxing procedures. The endurance limits or fatigue strengths obtained from the ordinary *S-N* diagrams of each material are listed as well as the stresses at which the coaxing experiments were begun. The various coaxing procedures utilized cycle increments of two million and ten million cycles and also four different values of stress increment as indicated. Values of the coaxing failure-stress that were obtained for different combinations of these stress and cycle increments are listed in the corresponding places in the table.

The coaxing failure stress for the combination of a 500 psi stress increment with a cycle increment of ten million was not determined since this would have required an extremely long time in testing. However basic differences in the response of the materials to coaxing were clearly shown by the testing procedures which required less time. For convenient reference, the materials listed in Table III have been separated into two groups. The first three metals listed are those which had their failure stress increased by the coaxing processes while the last three were apparently unaffected by coaxing.

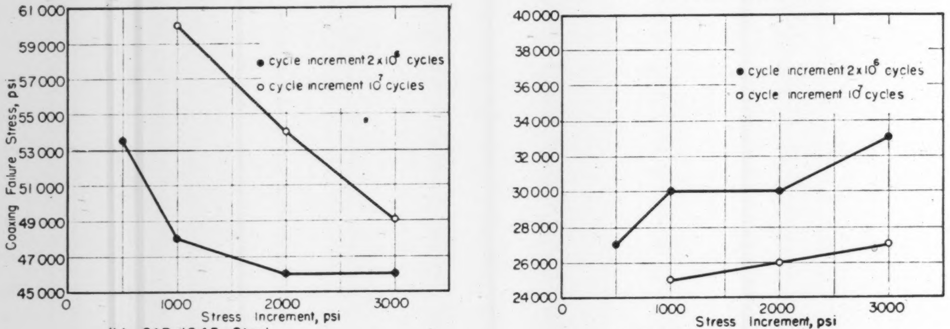
In order to simplify interpretation of the results given in Table III, the effect of the different stress and cycle increments on the failure stress for each material is shown graphically in Figs. 4(*a*, *b*, *c*, *d*, *e*, *f*). The ordinate in these figures represents the coaxing failure-stress of the metal and the abscissa indicates the stress increment used. Each point in the diagram represents the results obtained from a single test specimen. The specimens subjected to a cycle increment of two million are represented by the solid black dots while those which received a cycle increment of ten million are represented by the open circles.

Results obtained from tests of the metals susceptible to coaxing are presented in Figs. 4(*a*, *b*, and *c*). It may be seen that there were certain trends in the data which were characteristic of these three metals. For a given cycle increment, decreasing the stress increment has resulted in an increase in the coaxing failure stress. Increasing the cycle increment for a given value of stress increment has also resulted in an increase in the coaxing failure-stress.



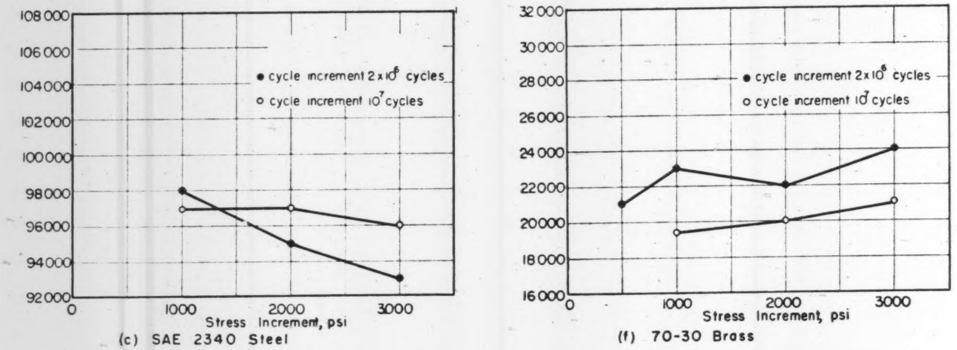
(a) Ingot Iron "B" Specimens

(d) Ingot Iron "A" Specimens



(b) SAE 1045 Steel

(e) 75S-T6 Aluminum Alloy



(c) SAE 2340 Steel

(f) 70-30 Brass

FIG. 4.—Influence of Cycle Increment and Stress Increment on Coaxing Failure Stress.

In Figs. 4(*d*, *e* and *f*), results are shown for materials which did not appear to have their fatigue resistance improved by the coaxing procedure. Here it is seen that changing the values of cycle and stress increments produced fundamentally different effects on the failure stress than was shown in the previous three figures. For these metals, increasing the cycle increment or decreasing the stress increment reduced the failure-stress. This indicated that the fatigue resistance of these materials was not improved by the coaxing procedures used. Differences in the failure-stress obtained by changing the stress increment sometimes amounted to only a few thousand psi. In view of the known statistical variation in fatigue properties, there may then be some question as to the accuracy of these failure-stress values. It was felt, however, that the fact that data from all three of the metals in this latter group show the same general trend indicated that the results were not due to chance alone but represented a real material effect. The effects of changing the cycle increment are more clearly indicated than those of changing the stress increment. Increasing the cycle increment for the metals shown in Figs. 4(*d*, *e*, *f*), invariably resulted in a decrease in the failure-stress which was quite the opposite of the trend found in the metals of the first group (Figs. 4(*a*, *b*, *c*)).

One of the points which should be clarified at this time is that the ingot iron "A" and "B" specimens were prepared from the same heat of material. Data obtained from the "B" specimens (Fig. 4(*a*)) indicated that the fatigue resistance was definitely improved by the coaxing procedure while the resistance of the "A" specimens (Fig. 4(*d*)) was not improved. An explanation for this variation in behavior of the two groups seems to lie in the different sequence of the heat-treating and machining operations used in preparing the specimens. The "B" specimens were heat-treated subsequent to the machining and polishing operations. This sequence of preparation left the metal at the surface of the test section in an annealed condition which was capable of being strengthened by strain-aging. On the other hand, the ingot iron "A" specimens were machined and polished mechanically *after* the annealing heat-treatment. The machining process produced a layer of deformed metal on the test section which was then slightly heated by abrasive action during the process of mechanical polishing. This action and the considerable time interval which elapsed before testing resulted in a layer or "skin" of strain-aged metal on the surface of the test section. This surface had a relatively large effect on the fatigue data since the tests were conducted in rotating bending machines which subject only the outer fiber of the specimen to maximum stress. Therefore, in fatigue and coaxing tests, ingot iron "A" specimens may be considered as strained and aged *prior* to testing. Further evidence of this effect may be found in the fact that the ordinary fatigue limit of the "B" specimens was 24,000 psi while that of the "A" specimens was 37,000 psi.

INTERPRETATION OF TEST RESULTS

As mentioned previously, the mechanism by which fatigue damage is developed in a metal seems to be associated with slip. Studies of the formation of fatigue cracks by use of the optical or electron microscopes have disclosed that initiation of the crack is preceded by the formation of slip lines or by other indications of plastic deformation. Cracks form within localized zones which have suffered severe plastic deformation and on a microscopic scale have usually been observed to grow within and parallel to the slip lines in these areas. In general, it is believed that any process which will prevent or quickly inhibit the continuation of slip in the metal will also increase its fatigue strength. In attempting to account for the coaxing phenomenon, then, it is apparent that the process of understressing must somehow increase the elastic limit or resistance to slip of these localized weak spots in which fatigue damage begins. Work-hardening of the metal has been suggested as a possible explanation of the coaxing effect. This, however, is not easily accepted since the cracks are observed to form in the very regions which should be work-hardened most.

A more reasonable explanation of the coaxing effect appears to be the phenomenon of strain-aging which is found in many of the common ferrous metals. Strain-aging may be observed in mild steel for example, when it is first strained plastically in tension by some small amount and then allowed to rest or "age" at room temperature for several days. On retesting the metal in tension, it is found that the elastic limit of the metal has been increased to a value greater than that of the unstrained material. The increase in the elastic strength is considerably larger than that which may be accounted for by work-hardening alone; this is one of the characteristic results of the strain-aging effect. Increasing the elastic strength of the metal by strain-aging will also increase its fatigue strength as shown by the work of Körber and Hempel (12). A review of the literature has disclosed that those metals which had their fatigue life increased by rest periods or which exhibited a strong coaxing effect were ferrous metals which presumably could be strengthened by strain-aging in the local regions where fatigue damage initiates.

Results of the present study indicated that those metals which had a matrix of ferrite capable of further strain-aging had their fatigue resistance improved by a coaxing procedure. The metals which were work-hardenable but which had little or no capacity for strain-aging (or for further aging) showed no coaxing effect. The annealed 70-30 brass, for example, had an excellent capacity for being strengthened by work-hardening and yet did not have its fatigue resistance increased by coaxing.

In the present study, data obtained from the metals which had their fatigue resistance improved by coaxing indicated the following:

1. Increasing the cycle increment increased the coaxing failure-stress.
2. Decreasing the stress increment increased the coaxing failure-stress.

It is believed that these two results may be related through a common factor of *time*. Increasing the cycle increment or decreasing the value of the stress increment simply provided the material with more time during which a strain-aging process could continue and thus resulted in a greater improvement in the localized elastic strength of the metal.

According to the results obtained in the present investigation, the effect of the coaxing process on a metal susceptible to strain-aging might occur in somewhat the following manner. At the initially small cyclic stress amplitudes, slip occurs in only a few localized weak regions which happen to contain crystals favorably oriented for slip. Plastic deformation by slip slightly relieves the stress in these few areas, and the slip process does not continue since the initial stress was relatively small. The elastic strength of these deformed areas is then gradually increased by strain-aging (which occurs during subsequent cycles of stress) until these regions are finally more resistant to slip than the surrounding metal. When the load is increased slightly according to a coaxing procedure, yielding occurs in new areas which in turn are strengthened by strain-aging. This process of gradually improving fatigue resistance by strengthening the "weakest links" continues until finally a stress is reached at which slip is initiated in regions which no longer have the capacity for further strengthening by strain-aging and fatigue crack development then begins.

SUMMARY AND CONCLUSIONS

A study was made of the effect of coaxing procedures on the fatigue resistance of a number of metals which had various differences in their ability to be strengthened by strain-aging and in their capacities to work-harden. These metals were ingot iron (in both unstrained and strained-and-aged conditions), SAE 1045 steel, SAE 2340 steel, 75S-T6 aluminum alloy and annealed 70-30 cartridge brass. The fatigue resistance of the unstrained ingot iron and the SAE 1045 and 2340 steels was considerably increased by coaxing while the fatigue resistance of strained-and-aged ingot iron, 75S-T6 aluminum alloy and 70-30 brass was not improved.

As a result of these studies, it was concluded that the coaxing effect in fatigue is due to a time-dependent localized strenthening of the metal by strain-aging which occurs during cyclic stressing at small stress amplitudes. From the standpoint of additional benefits in fatigue strength, the coaxing effect appears to furnish a very practical reason for gently "breaking in" new machinery providing that the components which are subjected to repeated stresses are formed of a metal which is capable of being strengthened by strain-aging.

Acknowledgment:

The research studies outlined in this report were conducted in the Department of Theoretical and Applied Mechanics, of which F. B. Seely is the Head, as a part of the work of the Engineering Experiment Station of the University of Illinois. The investigation was directed by T. J. Dolan and was sponsored by the Office of Naval Research, U. S. Navy under contract N6-ori-71, T.O. IV. The assistance of J. R. Owen, who prepared the figures, is gratefully acknowledged.

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DISCUSSION

Mr. J. O. Almen.[1]—Two explanations of the "coaxing" or understressing effect have been given, each of which, on the basis of the data presented by its proponents, appears to be quite logical. A third, and I believe a much more potent cause of this effect, can be readily demonstrated.

If we postulate that fatigue specimens start out in life afflicted with numerous highly localized residual stresses, usually spoken of as microstresses, such as are known to result from differing properties of crystals along their several axes, the actual local stresses within and on the surface of the specimen will be the sum of the nominal applied stress and the local residual stresses. In regions where residual microstresses act in the same or similar direction as the applied stress, the sum of the two often exceeds the static yield stress of the metal.

In addition to highly localized stresses, few specimens are free from macroresidual stresses. These, like the microstresses, augment the stress from external loads to produce tensile and compressive stresses of relatively great magnitudes. The normal result is that, when tested in fatigue, failure is hastened by the increased tensile resultant, particularly in the surface metal.

From measurements that I have made on steel specimens subjected to repeated unidirectional loads, plastic yielding occurs at stresses far below the static elastic limit of the metal. Specimens show continuous but decreasing dimensional changes for several million load applications even at stresses as low as 60 to 70 per cent of the static elastic limit. Yielding may affect only minute volumes of metal, but since they are numerous and since yielding occurs mainly in one direction under unidirectional loads, the sum of these plastic dimensional changes is sufficient to be easily measured.

In rotating-beam and other fatigue specimens subjected to reversed loads, no measurable change in specimen dimensions need appear, even though extensive plastic yielding occurs in local crystal aggregates. Local yielding must be expected in numerous aggregates, but since tensile and compressive yielding occur with substantially equal frequency, special techniques are required to measure their effects. Such measurements have been made by X-ray and by microscope, both showing local yielding.

The decreasing rate of plastic yielding with constant load magnitude and constant rate of load application indicates that the fatigue endurance limit is that nominal stress which approaches zero plastic yielding after one to ten million load applications. At higher stresses plastic yielding continues until fracture occurs.

Relatively rapid plastic yielding at higher nominal stresses damages the material by too great local slipping. If, however, the specimen is permitted to dissipate residual stresses at lower rates by temporarily reducing the applied loads, that is, by "coaxing" or "understressing," the damaging effects are reduced and the specimen exhibits greater fatigue strength.

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[1] Executive Consultant, Research Laboratory Division, General Motors Corp., Detroit, Mich.; present address, Sierra Madre, Calif.

The resulting increased endurance limit is still the nominal stress at which plastic yielding approaches zero.

Non-ferrous metals would not be expected to profit as much by understressing as steel because plastic yielding occurs at relatively lower stresses. It is probable that the dynamic elastic limit of non-ferrous metals, particularly aluminum and magnesium, approaches zero stress; hence they have no fatigue endurance limit.

MR. G. T. HORNE.[2]—It seems to me that the author's explanation of the effect of understressing based on strain aging and that of Mr. Epremian based on selectivity[3] have little in common, for the understressing effect in most materials is a much smaller one than the one which was originally found. In a material exhibiting strain aging, or structural changes of any sort with time (whether serving to increase or decrease strength), the selectivity factor must be overshadowed. It is the usual small understressing effect in stable materials that, I think, Mr. Epremian believes can be explained on the basis of selectivity.

About Mr. Almen's static-dynamic yield strength, what happens in those materials such as coarse pearlite or austenitic stainless steel which have endurance limits greater than static (even offset) yield strength? This is one of the problems with fatigue theories based on strength alone.

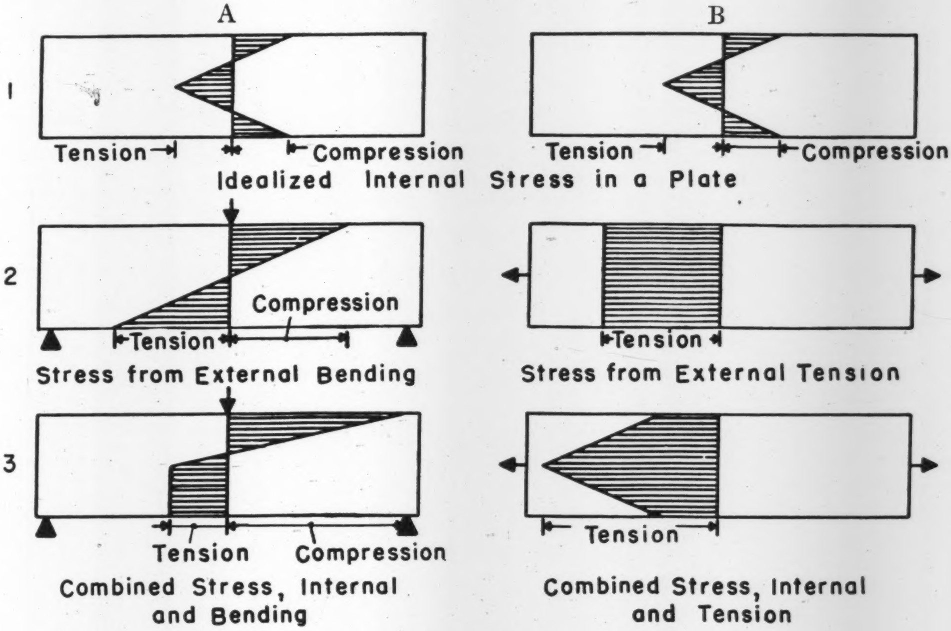
A
B
1
Tension
Compression
Tension
Compression
Idealized Internal Stress in a Plate
2
Compression
Tension
Stress from External Bending
Tension
Stress from External Tension
3
Tension
Compression
Combined Stress, Internal and Bending
Tension
Combined Stress, Internal and Tension

FIG. 5.—Tension Test Gives Wrong Answer.
A plate or a shaft residually stressed for best fatigue strength in bending or in torsion will often show inferior strength in a tension test.

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[2] Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa.

[3] E. Epremian and R. F. Mehl, "A Statistical Interpretation of the Understressing on Fatigue Strengths," Symposium on Fatigue with Emphasis on Statistical Approach II, Am. Soc. Testing Mats., p. 58 (1952). (Issued as separate publication, *STP No. 137*).

MR. ALMEN.—The difficulty anticipated by Mr. Horne with my theory on understressing ceases to be a problem when actual stresses are considered instead of nominal stresses. The matter can, I think, be best clarified by comparing the two series of stress diagrams shown in the accompanying Fig. 5.

Consider first the three diagrams at the left. The diagram *A-1* represents a residually stressed beam in which the upper and lower surfaces are residually stressed in compression and the central portion is residually stressed in tension. It is seen that the sum of the areas representing compressive stress is equal in area to the triangle representing tensile stress necessary to satisfy equilibrium conditions.

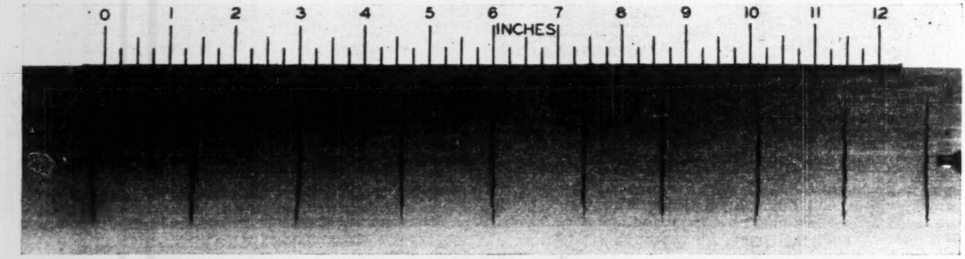

FIG. 6.—Internal Fractures in Cold-Rolled Bar.
Fractures caused by trapped internal tensile stress induced by cold rolling.

The diagram *A-2* represents a similar beam, not residually stressed, supporting a downward acting load as indicated by an arrow. The upper half of the beam is stressed in compression, the lower half in tension by the downward acting load. The surface stresses are arbitrarily made twice as great as the surface residual stresses in diagram *A-1*.

Diagram *A-3* represents a beam that is residually stressed as is shown in idagram *A-1* and that also supports an external load as shown in diagram *A-2*. Note that, as compared to the externally stressed beam *A-2*, the compressive stress on the upper surface is increased and that the tensile stress on the lower surface is decreased by the addition of residual stress.

Since fatigue failures result only from tensile stress, the fatigue strength of the beam *A-3* is increased, particularly to unidirectional loads.

The three diagrams at the right represent the effect of combining residual stress and axial tension. Diagram *B-1* represents residual stress identical with the residual stress in diagram *A-1*.

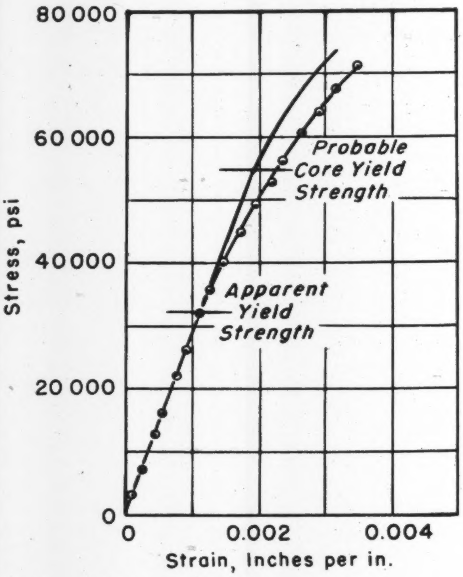

FIG. 7.—Stress-Strain Curve for Carburized Bar.

Diagram *B-2* represents a beam similar to *B-1* without residual stress but loaded in axial tension to the same stress as the surface tension shown in diagram *A-2*.

Although the diagrams shown in Fig. 5 are intended only to present the problem in a simple form, the important stress relationships are in no sense exaggerated. In fact, measurements have shown even greater differences between the nominal stress and the actual stress than are indicated in diagrams *A-3* and *B-3*.

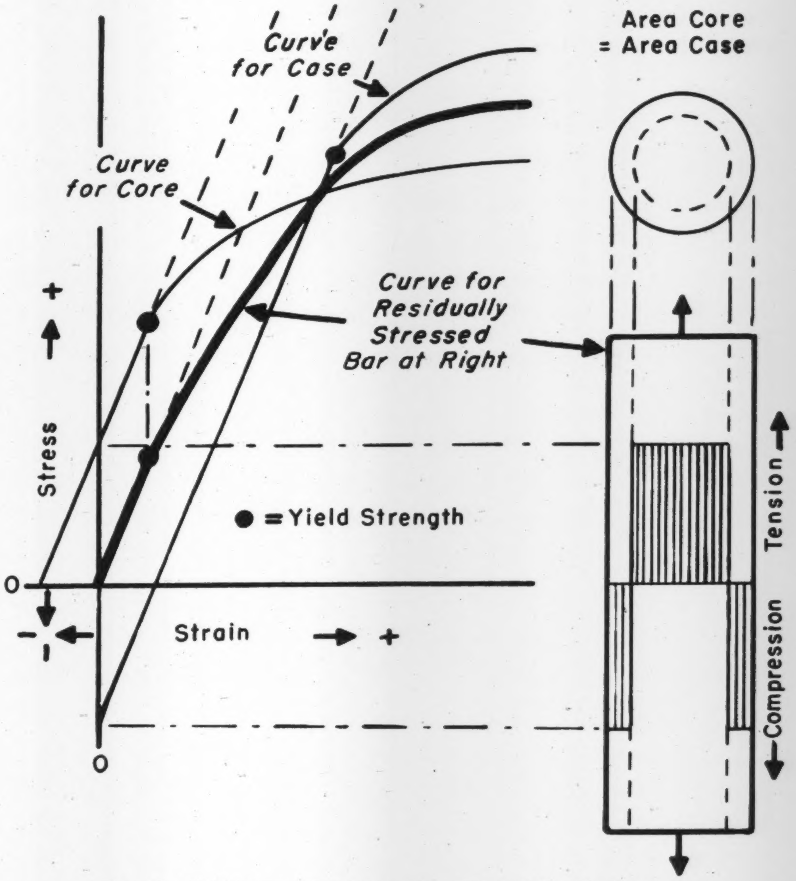
Curve for Case
Area Core
= Area Case
Curve for Core
Curve for Residually Stressed Bar at Right
+
Stress
● = Yield Strength
0
Strain
+
0
Tension
Compression

FIG. 8.—Yield May Be Adversely Affected by Residual Stress.

Diagram *B-3* represents the algebraic sum of the residual stresses seen in diagram *B-1* and the external tensile stress seen in diagram *B-2*. Note that although the nominal tensile stress in diagram *B-3* is the same as the nominal tensile stress in diagram *A-3*, the actual tensile stress in the former is three times as great as in the latter.

Two $1\frac{3}{4}$-in. square beams of S.A.E. 1030 steel fully annealed to a Rockwell hardness of B 65 were hammer peened on two opposite faces. One specimen was fatigue tested in comparison to a similar beam that had not been peened. The second peened specimen was dissected by removing many very thin layers of metal and measuring the deformation of the remainder after each layer was removed. The residual stress originally in the specimen was then reconstructed from the dissection measurements.

The residual compressive stress at the surface was found to be 21,000 psi, increasing to a maximum of 41,000 psi at a depth of 0.1 in. The residual tensile stress at midsection was 24,000 psi. The nominal bending stress that was applied to the companion beam during the fatigue test was 35,500 psi.

The combined stress corresponding to diagrams *A-3* and *B-3* of Fig. 5 would be 35,500 − 21,000 = 14,500 psi tension at the surface and 24,000 + 35,500 = 59,500 psi tension at midsection if direct tension had been applied as indicated in diagram *B-2* of Fig. 5.

Note that the actual tensile stress from an applied axial load of 35,500 psi would have been nearly 60,000 psi. If this seems to be an exceptional case it is only necessary to recall that the internal residual tensile stress often exceeds the ultimate strength of the metal. The longitudinal section of a cylindrical bar shown in Fig. 6 shows fractures that were found in the bar as received from the mill.

Among the data presented by H. F. Moore and W. J. Alleman in a paper[4] dealing with carburized fatigue specimens are stress-strain measurements plotted in Fig. 7. Note that in axial tension the specimen had an apparent yield strength of less than 25,000 psi although the "true" yield strength, estimated from the hardness of the core, was approximately 55,000 psi. This discrepancy, which was not explained by the authors, was due to the residual tensile stress in the core that was developed by the volume increase of the carburized case upon hardening.

A similar loss of yield strength in a residually stressed specimen was described by Heyn in the *Journal*, Institute of Metals, Volume 12, No. 2, 1914. Figure 8 is based on the work of Heyn but is simplified to facilitate description. The specimen at the right is assumed to be a cylinder in which the residual tensile stress in the core is equal to the residual compressive stress in the case. The heavy line of the stress-strain curve at the left represents the measured results of an axial tensile load on the specimen. The left-most curve represents the true stress-strain curve of the core and the curve at the right represents the true stress-strain of the case.

The origin of the true stress-strain curve for the core lies to the left of the ordinate of the normal plot by the amount of the residual tension in the core. Its true yield stress is seen to be twice as great as the apparent yield stress of the whole specimen. The true yield stress of the case, if measurable without rupture of the core, is of no importance to this discussion.

Mr. Horne's question points to the inadequacy of conventional laboratory tests by which we seek to measure the worth of structural materials. It is no longer possible to base material requirements of modern machine elements on physical properties measured by tests intended for overdesigned static structures. We are like a pilot who navigates with a magnetic compass. He can make a landfall if his target is large enough and his gas holds out, but only good luck could lead him to any of the small Pacific islands if he should be so foolish as to try such a journey.

MR. FRANK A. MCCLINTOCK.[5]—Mr. Sinclair's paper seems to have shed light on what was previously a baffling subject.

I would like to ask something which

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[4] *Transactions*, Am. Soc. Steel Treating, Vol. 13, (1928).

[5] Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

probably has already occurred to him, whether tests run at different speeds might not also help to differentiate between the importance of the strain aging process and effects due to cold working. Tests at a higher speed should give a larger number of cycles to failure if time for plastic flow is important, whereas tests at a lower speed should allow more time for strain aging to occur.

MR. T. MCLEAN JASPER[6]—The value of the "coaxing" tests for certain metals is in establishing confidence in the endurance values when obtained in a way which represents service applications. The small endurance test specimen is not representative of the metal when it is used in structures of large dimension, and engineers who aim to apply endurance data in design are now well aware of this fact. The first tests I know of that indicated this coaxing phenomenon in steel are reported in *Bulletin No. 142* of the University of Illinois Engineering Experiment Station, p. 29, issued May 1924.

It was very clear at this time that if relatively high endurance values for certain steels were obtained by heat treatment or cold work, the coaxing method had practically no effect in improving matters. Maybe it is analogous of the fact that a food-filled youngster has no desire for more, whereas one who is hungry will eat well.

Another phenomenon in steel may also be allied to the above. It was discovered that when repeated stress was not fully reversed the apparent endurance limit in tension was considerably improved over that obtained for complete reversal. This is indicated in the tests reported by the writer in 1924: ASTM *Proceedings*, Vol. 24 of 1924, p. 613, and the discussion thereto presented. It is believed that in these tests the coaxing method is not likely to produce values much above the yield value of the metal. The only case that has come to my notice is that of Armco steel or iron, complete reversal endurance limit of which was reported as 26,000 psi and the yield as 19,000 psi.

In discussing these phenomena, it should be realized that we are discussing tests performed at normal atmospheric temperatures. It is believed that if, for instance, fatigue were applied to steel at 900 F much of what is said about it at 60 F would not be true. It is also very apparent that the necessary work involved in obtaining the test values herein reported will not be directly applied in engineering designs because of the tedious procedure necessary to fulfill its requirements. Such tests, however, contribute to the knowledge of the metals used to carry most engineering loads.

Mr. G. M. SINCLAIR (*author's closure*).—Mr. Almen gives an interesting interpretation of understressing and coaxing effects in fatigue which in a number of ways is similar to the interpretation given in this paper. We are in agreement in considering cycle dependent fatigue failure to initiate through yielding and in considering the resulting deformations leading to failure to be highly localized. I must differ, however, with the heavy emphasis which Mr. Almen places on the influence of residual stress. Without question, residual stresses exert an influence on the fatigue strength of metals and possibly in some instances may be the most important single factor determining failure (high hardness steel parts, for example). Nevertheless, to attempt to interpret all fatigue phenomena in terms of residual stress and to ignore the characteristic behavior of the material itself may lead to erroneous conclusions.

An interesting example of the relative importance of residual stress and strain aging in mild steel is found in some unpublished work done by Mr. Ralph King of the Caterpillar Tractor Co. Mr. King produced macroresidual stresses in flat plate cantilever-beam fatigue specimens by controlled plastic bending which was done before testing. The specimens were then subjected to fatigue stressing in such a way that the residual tensile stress would add to the imposed cyclic tensile stress in bending. It was anticipated that the fatigue limit of the metal would be lowered by an amount approximately equal to the residual tensile stress in the specimen. Actually, however, it was found that the fatigue limit had *increased* by somewhat more than 10 per cent. It seems reasonable to conclude then that some form of strengthening has occurred in the metal which was more than sufficient to offset the residual tensile stress. I suggest that this strengthening came about simply by strain aging which could occur during the relatively long period of storage of the plastically strained specimens at room temperature prior to testing.

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[6] Consulting Engineer, Milwaukee, Wis.

Further support for the strain aging hypothesis may be found in the long-established fact that the fatigue limit of low-carbon steel reaches a maximum in the temperature range of 400 to 800 F and then decreases at higher temperatures. The residual stress pattern in the specimens would have to undergo a most extraordinary and unlikely series of changes with temperature in order to account for this maximum.

The discussions by Mr. Horne and by Mr. Jasper emphasize several other observations which are directly interpretable in terms of the known effects of strain aging on the flow strength of metals but which cannot be accounted for unambiguously by the concepts of residual stress.

These are:

1. The fatigue limit of high-strength heat-treated steels appears to benefit very little, if at all, by understressing or coaxing while the strength of annealed low-carbon steels may be greatly increased by the same testing procedures.

2. The fatigue limit of annealed ingot iron is significantly larger than its static yield strength. This is not the case for metallurgically stable materials.

3. Results of the present experiments indicate a distinct influence of time on the effectiveness of the coaxing procedures in those cases in which fatigue strength was improved.

There have been two or three instances in which small increases in the fatigue strength of stable aluminum alloys were reported and attributed to the supposed beneficial effects of understressing. Regarding this, I agree with Mr. Horne and feel that the selectivity theory advanced by Epremian and Mehl[3] satisfactorily explains the reports. In these few cases it appears likely that the slight improvement in strength attributed to understressing was apparent rather than real.

Mr. McClintock's proposal to differentiate between the effects of cold work and strain aging by making tests at different speeds appears sound but might be quite difficult to carry out experimentally. An equivalent method would be to conduct the tests over a series of different temperatures, in which case I would expect the fatigue limit and life of an aging metal to pass through a definite maxima, while those of a non-aging but work-hardenable metal should exhibit no such discontinuity.

In conclusion it may be of interest to note that the refractory metals molybdenum and tungsten containing small amounts of nitrogen and carbon have been found to exhibit the upper and lower yield point effect familiar in low-carbon steels. It appears likely then that these metals will also be strengthened by coaxing within a restricted temperature range.

A STUDY OF FATIGUE OF STEELS IN THE FINITE REGION OF THE *S-N* CURVE[*]

By Walter G. Finch[1]

Synopsis

One chromium-molybdenum-vanadium and two chromium-nickel-molybdenum-vanadium gun steels were studied in repeated bending in order to define the shape and level of the finite region of the *S-N* curves between the yield and endurance strengths as affected by a number of factors such as notches, impact resistance (resistance to rupture at a striking velocity of 16 ft per sec), and tensile and yield strengths. Various types of notches were used in order to obtain various degrees of stress concentration, namely small radius, square shoulders, 90-deg V-notch and 45-deg V-notch.

The results of the experiments indicate that the fatigue curves for varying stress concentrations converge toward a point near the true tensile strength (ultimate load in tension divided by the instantaneous area at that load) of the material and at 20 to 40 cycles of stress reversal. In addition, the curves for fatigue strength reduction (fatigue notch) factors and stress reversals, namely, k_f-N also converge in the high-stress range to a value of unity between 20 and 40 cycles of repeated stress, thus indicating that the values of k_f obtained in the endurance or infinite range represent an upper limit, while the values obtained in the plastic region (above where the stress exceeds the elastic limit stress) represented a lower limit for the fatigue strength reduction factor.

S-N curves for the various steels enter the plastic region in the neighborhood of 600 to 6000 stress reversals, the former value for the most critical notched specimens, while the latter pertains to unnotched specimens. In the plastic region it was impossible to calculate true surface stresses due to the introduction of the stress concentrators, which caused plastic yielding to take place at the base of the notch.

Analyses made of the effect of mechanical properties on the shape and position of the *S-N* curves reveal, in general, that an increase in either impact resistance, yield or tensile strength, decreases the life in the finite range for notched specimens, the magnitude of which depends on the stress level where the operation is taking place.

Speed of stress reversals appeared to have no effect on the position of the *S-N* curves, although increased speed probably would decrease the finite life slightly due to heating up of the fatigue specimens.

A total of 268 specimens were tested, thus defining favorably the *S-N* scatter band for each type of steel. Due to excellent preparation of the fatigue testing specimens, little scattering was obtained in the testing results.

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[*] Presented at The Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.

The purpose of this investigation was (1) to examine a number of typical steels in order to define, with adequate precision, the shape and level of the finite region of the S-N curves between the yield and endurance strengths as affected by a number of factors such as notches, tensile and yield strengths, and impact resistance; (2) to obtain information on the relative shapes of these curves in the plastic region; (3) to obtain data on fatigue strength reduction factors at the endurance limit and at high stress; and (4) to extend the fatigue curves from approximately 5,000,000 cycles of repeated stress to the plastic region of few cycles of repeated stress.

"Fatigue" when used in conjunction with metals concerns the behavior of the latter when subjected to repeated stresses. Most engineering structures are subjected to repeated stresses that occur either rapidly or over a long period of time. Rotors of steam turbines, connecting rods and shafts of reciprocating engines, axles of automobiles, all undergo many cycles of repeated stresses over a short interval of time. On the other hand, girders and truss members of bridges, landing wheels of aircraft, and artillery cannon, are examples of parts that undergo relatively few cycles of repeated stresses in the lifetime of the piece.

Most machines and structural parts are subjected to millions or billions of cycles of repeated stress. In order for the parts to withstand such stresses, it has been found necessary to design machines or structural parts below the endurance strength of the materials in question, that is, the highest stress which, regardless of the number of times it is repeated, will not cause failure **(1)**.[2]

Practically all experimental fatigue work on steels for the past 100 years has concerned itself with the determination of the effect of various factors such as surface finish, notches, corrosion, size effect, temperature, and grain size on the endurance limit. It is evident that in order to determine the effect of these factors on the endurance limit it is necessary to subject fatigue specimens to millions of cycles of repeated stresses.

Not all machines or structural parts, however, are subjected to millions of cycles of repeated stress. Some parts may be subjected only to several thousands of cycles before their useful life is terminated by other factors. Artillery weapons used by our present-day military forces are typical examples since they are subjected to fatigue as a result of cyclic applications of stresses counted by the number of artillery rounds fired; the number, in general, being less than 40,000 cycles. Fatigue under such limited life is often termed "progressive fracture." Progressive fracture is dependent upon two factors, that is, the stress level at the bore surface and the resistance of the metal to the propagation of any cracks that may form in the highly-stressed regions of the land and grooves due to the powder and rotating band pressures.

In the conventional guns built prior to and at the beginning of World War II, the steel was so soft that the tube would wear out before fatigue failure occurred. Each time a microscopic fatigue crack started in the gun tube, the passing of the projectile through the tube would wear away the crack. Consequently, the tube was discarded because of erosion. Later on in World War II, it became necessary to increase the muzzle velocities of projectiles in order to get higher striking velocities on the targets. Reduction in the weight of the guns was also necessary to obtain better mobility. The latter was achieved by reducing the wall thickness of the tube and breech block.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 777.

Once a microscopic crack started in the thin-wall high-pressure guns, due to high stress concentrations at the junctures of lands and grooves, the cracks would propagate with the firing of each artillery round. Sooner or later the gun either blew up or was discarded because of this progressive stress damage.

TABLE I.—CHEMICAL ANALYSIS.

Steel	Chemical Composition, per cent								
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molydbenum	Vanadium
No. 1	0.29	0.69	0.011	0.018	0.20	0.09	0.96	0.55	0.08
No. 2	0.32	0.66	0.015	0.025	0.25	2.33	0.98	0.39	0.10
No. 3	0.36	0.72	0.016	0.042	0.30	2.02	0.45	0.36	0.08

TABLE II.—MECHANICAL PROPERTIES OF THE STEELS.

Steel	Elastic Limit, psi	Yield Strength, psi	Tensile Strength, psi (original area)	True Tensile Strength[a]	True Tensile Strength[b]	True Breaking Strength[c]	Rockwell Hardness Number	Elongation in 2 in., per cent	Reduction in Area, per cent	Charpy Impact Resistance, Transverse ft-lb	Heat Treatment
No. 1	105 000	110 000	140 500	262 000	178 000	205 000	C-25	16	46.2	5	[e]
No. 2[d]	135 000	140 000	165 000	270 000	211 600	223 000	C-30	14	31.5	25	[f]
No. 3	138 000	146 000	181 000	265 000	232 300	231 000	C-30	13	35.5	18	[g]

[a] National Bureau of Standards (true tensile strength = ultimate load divided by final area).

[b] Watertown Arsenal (true tensile strength = ultimate load divided by instantaneous area at that load).

[c] National Bureau of Standards (true breaking strength = breaking load divided by final area at that load).

[d] Microstructures of this steel showed mainly tempered martensite with some evidence of tempered bainitic structures. There was a normal distribution and content of non-metallics.

[e] Heated to 1650F in 12 hr; held 8 hr; quenched in oil; heated to 1150F in 8½ hr; held 8 hr; pit cooled.

[f] Equalized to 1560F; furnace cooled to 650F; heated to 1625 F in 9 hr; held 15 hr; air cooled to 640F; heated to 1350F in 8 hr; held 15 hr (spheroidize); air cooled to room temperature; heated to 1510F in 10 hr; held 9 hr; quenched in soluble oil; heated to 1080F in 8 hr; held 8 hr; pit cooled.

[g] Quenching temperature 1625F; held 8 hr; medium water quenched to below 300F; draw temperature 1090F; held 20 hr; medium cooled to 100F; straightened; pit cooled.

SELECTION OF MATERIAL FOR SPECIMENS

One chromium-molybdenum-vanadium and two chromium-nickel-molybdenum-vanadium gun steels with Charpy impact strengths varying from 5 to 25 ft-lb were selected. These impact strengths were determined at a velocity of 16 ft per sec. Table I gives the chemical analyses of the three steels used, while Table II lists the mechanical properties of the same steels.

The three steels were heat treated to obtain 100 per cent tempered martensitic structures. The first steel was relatively ineffectively heat treated (pearlitic-tempered martensitic state) as observed from photomicrograph studies, elastic limit – tensile strength and yield strength – tensile strength ratios, and the abnormally low Charpy value.

The second and third steels were effectively heat treated as is clearly indicated by the high E.L./T.S. and the Y.S./T.S. ratios and the increased Charpy values as well as by photomicrographs for these steels. The heat treatment for steel No. 3 appeared to be much better than for steel No. 1, but somewhat poorer for steel No. 2. The heat treatments for the three steels are set forth in Table II.

PREPARATION OF FATIGUE SPECIMENS

In the design of repeated bending fatigue specimens, the stress was the controlling factor. In order to reach nominal stresses of 160,000 to 240,000 psi, it was necessary to reduce the diameter of the standard R. R. Moore specimen from 0.3 to 0.2 in. H. F. Moore (2) concluded from his experiments on size effect that a reduction of 0.1 in. in diameter of a steel specimen would increase the fatigue strength by approximately 1 per cent.

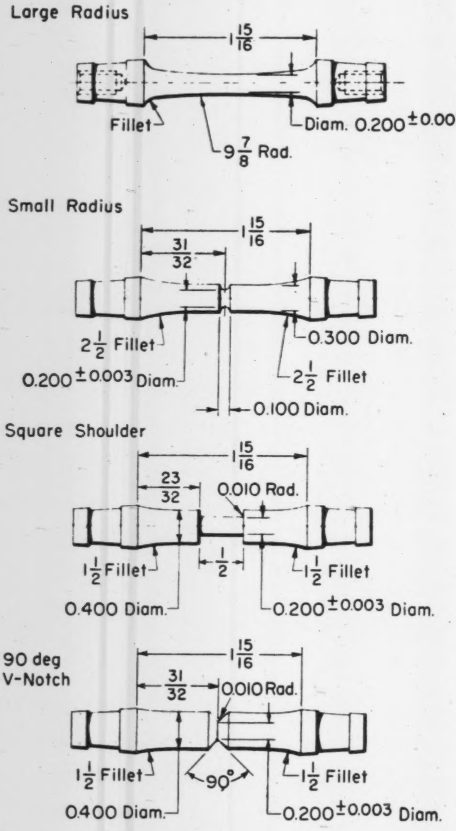
Large Radius
1 15/16
Fillet
Diam. 0.200 ± 0.003
9 7/8 Rad.
Small Radius
1 15/16
31/32
2 1/2 Fillet
0.300 Diam.
0.200 ± 0.003 Diam.
2 1/2 Fillet
0.100 Diam.
Square Shoulder
1 15/16
23/32
0.010 Rad.
1 1/2 Fillet
1/2
1 1/2 Fillet
0.400 Diam.
0.200 ± 0.003 Diam.
90 deg V-Notch
1 15/16
31/32
0.010 Rad.
1 1/2 Fillet
90°
1 1/2 Fillet
0.400 Diam.
0.200 ± 0.003 Diam.

FIG. 1.—Fatigue Specimens.

Figure 1 shows the various types of fatigue specimens used for different degrees of stress concentration. Four different types of specimens were designed for each steel as indicated in Table III.

The different types of specimens were designed so that the effect of stress concentration could be studied and data obtained as to the effect of the stress concentration at the root of the notch on cycle life.

The specimens were made from small, $\frac{1}{2}$-in. metal cylinders cut out of disks taken from three different 76-mm gun tubes. These cylinders were located in the mid-positions of the disks and in the transverse direction.

Extreme care was taken to see that the tapered ends of the specimens were accurately made. This was necessary in order to eliminate any vibrations in the experimental equipment that would give poor test results and prevent the test spindles from being worn out of round.

TABLE III.—TYPE OF SPECIMEN.

Steel	Type of Specimen				
No. 1.......	Large radius		Square shoulder	90-deg V	45-deg V
No. 2.......	Large radius	Small radius	Square shoulder	90-deg V	
No. 3.......	Large radius	Small radius	Square shoulder		45-deg V

The nine $\frac{7}{8}$-in. fatigue specimens were prepared in accordance with customary preparations (1).

In the preparation of the square shoulder specimens, the root base radii at the junctures of the gage section were carefully ground in by means of a copper wire of 0.01-in. radius covered with emery dust. The section included between the shoulders was polished with carborundum paper. In addition, the root-base radius of the small radius type, 45-deg and 90-deg V-notch specimens were ground in in a manner similar to that used for the preparation of the square shoulder specimens, with a 0.05-in. radius copper wire being used for the small radius type and a 0.01-in. radius copper wire being used for the 45-deg and 90-deg types of specimens. The root-base radius was made to coincide with the notch-base radius by first grinding in the radius and then cutting the notch sides with a sharp tool.

TABLE IV.—THEORETICAL AND FATIGUE STRENGTH REDUCTION FACTORS.

Type of specimen	Stress Concentration Factor						
	Estimated Theoretical	Determined Experimentally					
		Steel No. 1 (10,000 cycles)		Steel No. 2 (2400 cycles)		Steel No. 3 (5000 cycles)	
		Low Stress (E.L.)	High Stress (Y.S.)	Low Stress (E.L.)	High Stress (Y.S.)	Low Stress (E.L.)	High Stress (Y.S.)
Small radius	1.35 to 1.53	....	....	1.23	1.13	1.41	1.25
Square shoulder	2.40	1.33	1.19	1.67	1.50	1.71	1.59
90-deg V-notch	2.05 to 2.60	1.41	1.29	1.86	1.40	....	....
45-deg V-notch	2.70 to 3.25	1.43	1.31	....	....	2.24	1.42

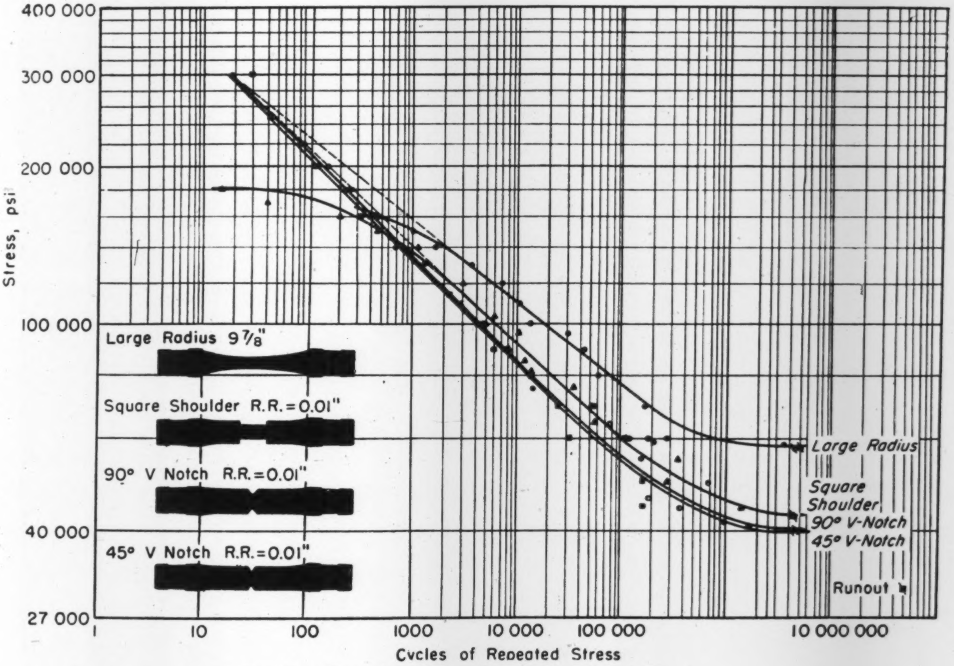

FIG. 2.—Rotating-Beam Specimens, Steel No. 1.

METHOD OF TESTING AND TEST PROCEDURE

The rotating bending test used in these tests was similar to that outlined in the ASTM Manual on Fatigue Testing (1).

Sample Calculations:

"Fatigue strength reduction factors" (sometimes called "fatigue notch factors") in either the finite or infinite range were calculated as follows:

(*a*) Fatigue strength reduction factor

at a point in the finite region. If for 1000 cycles of repeated stress, the large radius type of specimen for steel No. 2 failed at 120,000 psi and the 90-deg V-notch specimen ruptured at 79,000 psi, then the fatigue strength reduction factor in the finite region for 1000 cycles is:

$$k_f = \frac{120{,}000}{79{,}000} = 1.52$$

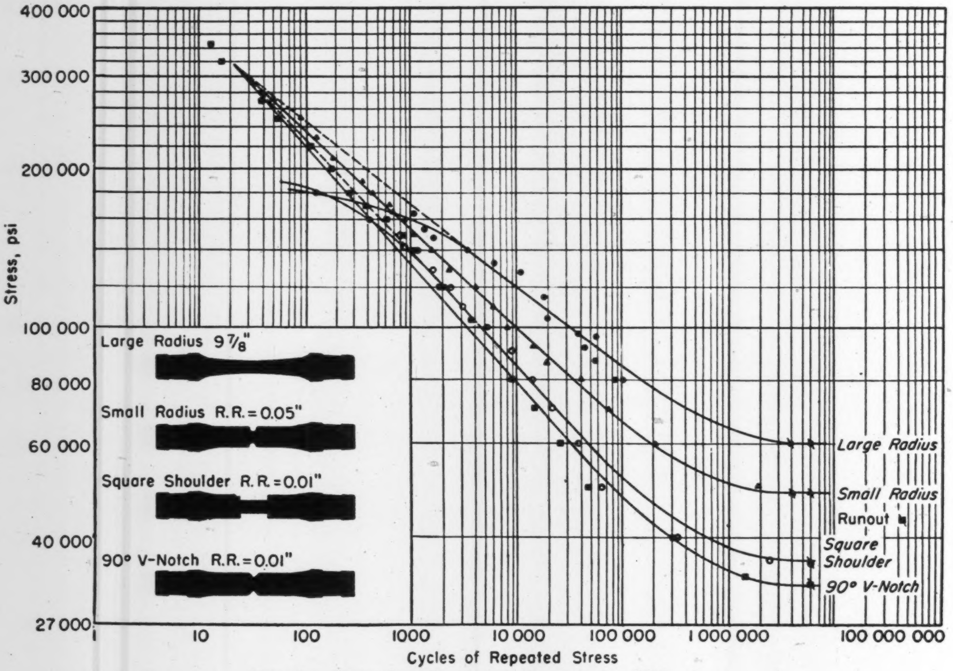

FIG. 3.—Rotating-Beam Specimens, Steel No. 2.

(*b*) Fatigue strength reduction factor in infinite region. If the endurance limit stress for an unnotched specimen (steel No. 2) is 80,000 psi, and for a small radius type is 48,000 psi, then the fatigue strength reduction factor at the endurance limit is given by

$$k_f = \frac{\text{Endurance Stress of Unnotched Specimen}}{\text{Endurance Stress of Notched Specimen}}$$

$$\text{or } k_f = \frac{80000}{48000} = 1.66$$

In Table IV are listed the estimated theoretical factors (3, 4, 5, 6) and the observed (experimentally determined) fatigue strength reduction factors at the endurance limit and yield strength stresses.

TEST RESULTS

In Figs. 2, 3, and 4 are plotted on log-log paper the test results obtained for the three steels. At high stresses it is to be noted that the curves for the large radius and square shoulder types of specimens do not continue upward in a straight line but instead, curve off to the left. At a small number of cycles they cross over each other and become horizontal.

This sudden change of direction above the elastic limit may possibly be attributed to a plastic deformation taking place in the specimens with increase in load. Large radius and square shoulder types of specimens are not as rigid as the 45-deg V-notch, 90-deg V-notch and small radius types of specimens; consequently, they are deflected more. In the large radius test specimen accurate readings could only be taken up to the yield strength before the machine was stopped due to the deflection of the specimen.

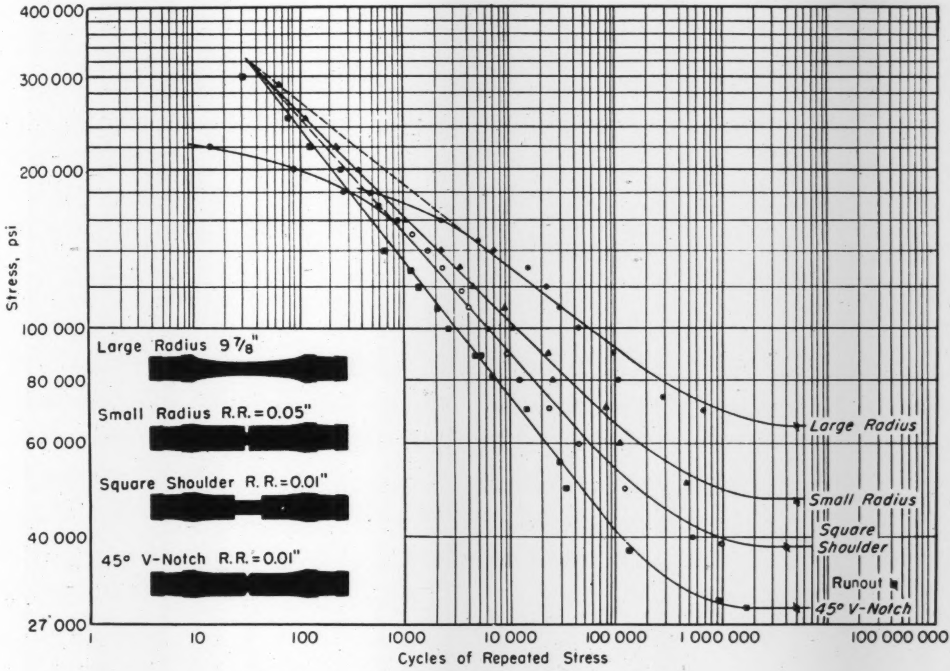

FIG. 4.—Rotating-Beam Specimens, Steel No. 3.

The curves for the 45-deg V-notch, 90-deg V-notch, and small radius type specimens tend to converge to a point at a few cycles at high stresses. (The square shoulder type specimen has large stress concentrations adjacent to the notch at higher stresses. However, it was impossible to continue the curves upward because of the large deflections at high loads for this type specimen.) Actually, however, these curves do not cross over each other. They tend, instead, to become parallel. If the curves for the large radius and square shoulder units in the elastic region are projected upward for comparison purposes, they tend to radiate from the same point as the curves for the 45-deg V-notch, 90-deg V-notch, and small radius type of specimens.

The specimens that did not fracture in less than 4,000,000 to 5,000,000 cycles of repeated stresses have been indicated by drawing a 45-deg line through each point that represents the specimen. Statistical curves were drawn through the test points in both the finite and the infinite regions.

In Fig. 5 the fatigue curves from Figs. 2, 3, and 4 for all three steels are superimposed on the same log-log plot. Actual test points were not shown since so many points would distract from the experimental curves.

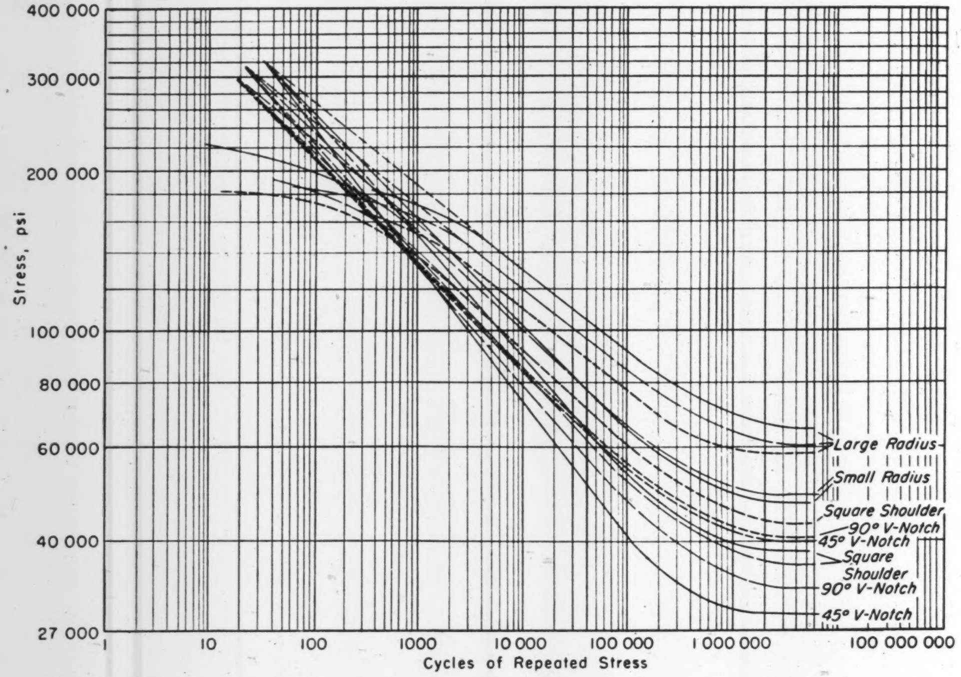

FIG. 5.—Rotating-Beam Specimens, Fatigue Curves of Three Different Cr, Ni, Mo, V Steels.

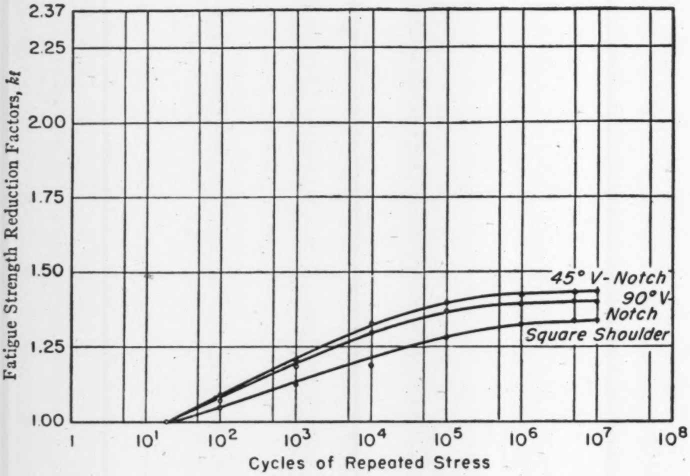

FIG. 6.—Variation of k_f with Number of Cycles of Repeated Stress for Steel No. 1.

Figures 6, 7, and 8 show the variation of the fatigue strength reduction factor, k_f, with the number of cycles of repeated stress for all three steels in both the finite and infinite regions, while in Fig. 9 all of these curves are shown together. These curves were determined by taking the ratio of the stress ordinates at 1000, 10,000, 100,000, 1,000,000, and 10,000,000 cycles of repeated stress. Since the fatigue strength reduction factor is a function of stress, it is also a function of stress, it is also a function of load. By using this principle the fatigue strength reduction factors were computed in both the plastic and elastic regions, independent of the stress magnitudes.

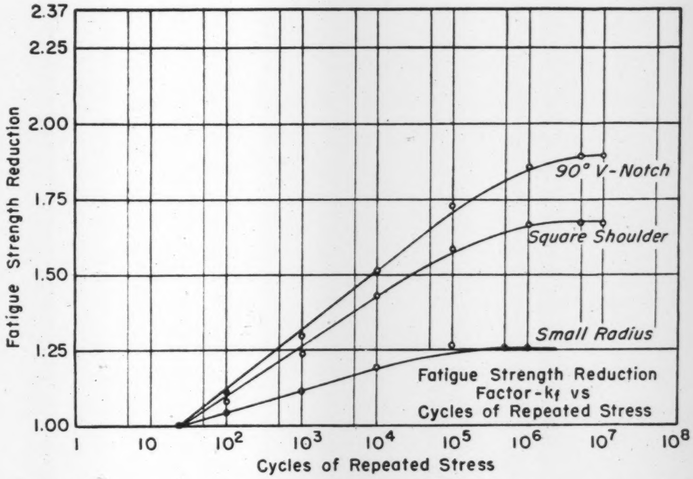

FIG. 7.—Variation of k_f with Number of Cycles of Repeated Stress for Steel No. 2.

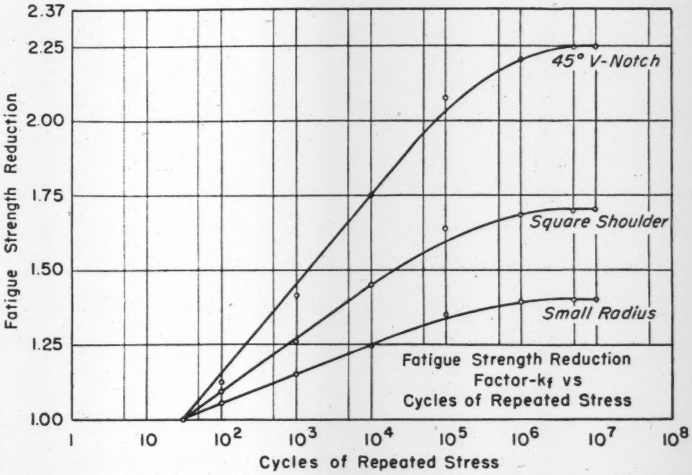

FIG. 8.—Variation of k_f with Number of Cycles of Repeated Stress for Steel No. 3.

Table V lists the stresses corresponding to the endurance limit and the fatigue strength reduction factors for the three steels in the infinite range.

DISCUSSION OF RESULTS

As previously mentioned, the nominal stresses at the outermost fibers of the test specimens, were computed from the simple beam or flexural formula.

The validity of this equation depends on the assumption that:

(*a*) The stress varies linearly from zero at the neutral axis to the maximum at the surface of the test unit.

(*b*) No stress concentrators are present in the test unit. When the maximum stress exceeds the elastic limit of the steel, the first assumption is violated because the stress is no longer proportional to the strain and, therefore, no longer follows Hooke's law. Thus, all of the values of stress which are shown as higher than the yield stresses in Figs. 2, 3, 4, and 5 are not exactly correct.

TABLE V.—FATIGUE STRENGTH REDUCTION FACTORS, k_f, IN INFINITE REGION.

Type of specimen	Steel No. 1		Steel No. 2		Steel No. 3	
	Endurance Limit, psi	Fatigue Strength Reduction Factor	Endurance Limit, psi	Fatigue Strength Reduction Factor	Endurance Limit, psi	Fatigue Strength Reduction Factor
Large radius	58 700	1.00	60 200	1.00	65 000	1.00
Small radius	...	...	48 000	1.25	46 000	1.41
Square shoulder	43 000	1.35	35 800	1.67	38 000	1.71
90-deg V-notch	40 500	1.41	32 300	1.88	...	...
45-deg V-notch	40 600	1.43	...	...	29 000	2.24

The bending moment equation was used in both the elastic and plastic regions for calculations of the surface stresses. In using this equation, no consideration was given to the effects of the notches, and the stresses were calculated from the equation as if the notches were not present. Thus while the same stress load was applied to each specimen on the same level, the number of stress cycles to failure was reduced with increase in notch severity because the stresses were actually higher at the same loads. Within the plastic range, however, this equation is not valid for calculations of stresses in notched specimens. It was used for comparison purposes only.

Figures 2, 3, 4, and 5 considered with tabulated static tension test data and with impact test data, Table II, tentatively indicate that an increase in either the tensile or yield strength of the large radius specimens shifts the fatigue curves upward, while an increase in the impact resistance shifts the fatigue curves to the right from the ordinate axis. This means that the life or number of stress reversals to failure is increased with increases in either the tensile or yield strength or impact resistance.

On the other hand, for the notched specimens the experiments tentatively indicate that an increase in the impact resistance has a tendency to lower the fatigue curves or to reduce the fatigue strength in both the finite and infinite regions. For example, on examining the *S-N* curves for the square shoulder specimens, it can be seen that the *S-N* curve for steel No. 1 is higher than those for steels Nos. 2 and 3. Since the impact resistance for steel No. 1 is 5 ft-lb while that for steels Nos. 2 and 3 are 23 and 18 ft-lb, respectively, it is evident that the *S-N* curve for steel No. 2 lies lower than for steels Nos. 1 and 3. A tentative conclusion is that an increase in impact resistance reduces the life or the number of stress reversals to rupture.

On increasing the severity of the stress concentration at the base of the notch, moreover, in the elastic part of the finite region, the slopes of the fatigue curves increase. All three steels showed this same general characteristic result in that increases of notch severity reduced the life of the specimen. From the theoretical and actual fatigue strength factors, the stress concentrators, with same root-base radius, increase from the large radius, small radius, square shoulder, 90-deg V-notch and 45-deg V-notch. The same results were obtained for all three steels. In the finite region the slope of the *S-N* curves increases with decrease in notch angle, provided the same root-base radius is used. Results from steel No. 1 indicate that the 45-deg V-notch specimens have an *S-N* curve of greater slope than the one for the 90-deg V-notch units with the same radius.

In general, for the same steel, the *S-N* curves for the various types of specimens converge to a point in the range of 20 to 40 cycles of stress in the plastic region at a stress magnitude that, in all probability, approximates the fracture strength or the true tensile strength of the material in question. Actual values were obtained from direct tension tests and compared with computed values. (See Table II.) The results indicate that they approximate one another. *S-N* curves for steel No. 3, which, incidentally, had the highest tensile strength, converged to a point slightly higher than for steels Nos. 2 and 1, with lower tensile strengths, respectively. Moreover, the *S-N* curves, for all three steels, radiated from points lying in the vicinity of approximtely 20 to 40 cycles in the high stress region. Whether or not this is characteristic of all metals other than steels can be proved only by further experiments of this nature.

A scatter band also radiates from the same number of cycles for each type of specimen. As the stress magnitude is increased, the scatter for a particular type of specimen decreases materially. For the hard materials used, the scatter was less than for the softer material. For example, less scatter was obtained from steels Nos. 2 and 3, than for steel No. 1. For all of the specimens made of the same steel, there is a scatter band that tends to converge to the same point from which the *S-N* curves radiate in the high stress region. The scatter band is decreased as the severity of the notch is increased, that is, less scatter is obtained with a 45-deg V-notch or 90-deg V-notch specimen than with a square shoulder or large radius specimen.

Endurance limits obtained in these experiments for both the unnotched and notched specimens agree remarkably well with the results obtained by other investigators (1). Compilation of results from other experiments indicates that the endurance limit or fatigue stress for 10,000,000 cycles for polished, unnotched specimens should be between 35 and 50 per cent of the tensile strengths of the steel material (over the range of tensile strengths studied). Endurance limits obtained from the present experiments were in the neighborhood of 36 to 38 per cent. This range falls within the aforementioned range obtained by other investigators. For severely notched specimens, on the other hand, the endurance limits obtained in other experiments were between 15 and 25 per cent of the tensile strengths (the former value for the less critically notched specimens represented by the square shoulder type, the latter for the more critically notched specimens represented by the 45-deg V-notch type). Results of the present experiments indicate that the 45-deg V-notch specimens give fatigue strengths varying from 16 to 28 per cent for steels

Nos. 3 and 1, respectively; while the square shoulder type gave fatigue strengths of 22 per cent for steels Nos. 2 and 3. Steel No. 1 gave a value of 31 per cent. However, as previously mentioned, this steel was poorly heat treated, being in a pearlitic-martensitic state instead of a completely tempered martensitic state.

The equation found to fit best the experimental data statistically in the elastic part of the finite and infinite regions was of the general form:

$$S = S_e + bN^r$$

where:

S and N = stress and number of cycles of repeated stress, respectively, and

S_e, b, and r are constants for the particular material, S_e being the endurance limit stress determined experimentally, and b and r constants obtained mathematically.

By the method of least squares, the above equation reduces to:

$$n \cdot \log b + r \cdot \Sigma \log N = \Sigma \log S \quad \ldots (1)$$

and

$$\log b \cdot \Sigma \log N + r \cdot \Sigma (\log N)^2 = \Sigma \log N \cdot \log S \quad \ldots\ldots\ldots\ldots (2)$$

Equations[3] 1 and 2 can now be used to determine the values of the constants b and r. However, before actually applying these equations, the value S_e was subtracted from each value of S.

On utilizing the above equations within the yield strength region, the following empirical equations were obtained for the three steels:

Steel No. 1

Large radius:

$$S = 58{,}000 + 2{,}010{,}000\ N^{-0.4012}$$

Square shoulder:

$$S = 43{,}000 + 2{,}720{,}000\ N^{-0.442}$$

90-deg V-notch:

$$S = 41{,}000 + 2{,}850{,}000\ N^{-0.4491}$$

45-deg V-notch:

$$S = 40{,}600 + 2{,}900{,}000\ N^{-0.4530}$$

Steel No. 2

Large radius:

$$S = 60{,}000 + 1{,}779{,}000\ N^{-0.3787}$$

Small radius:

$$S = 48{,}000 + 2{,}240{,}000\ N^{-0.4210}$$

Square shoulder:

$$S = 35{,}800 + 3{,}740{,}000\ N^{-0.4904}$$

90-deg V-notch:

$$S = 32{,}200 + 4{,}375{,}000\ N^{-0.5160}$$

Steel No. 3

Large radius:

$$S = 65{,}000 + 1{,}151{,}000\ N^{-0.3610}$$

Small radius:

$$S = 46{,}000 + 2{,}574{,}000\ N^{-0.4383}$$

Square shoulder:

$$S = 38{,}000 + 3{,}431{,}000\ N^{-0.4824}$$

45-deg V-notch:

$$S = 29{,}000 + 5{,}004{,}000\ N^{-0.5314}$$

Empirical equations derived from the S-N curves approximate the experimental data within ±6 per cent from the yield to the endurance strength regions. The first term of these equations represents the endurance stress in the infinite region, while the second is for the stress in the finite region. From these equations it can be seen that as the endurance limit stress term is reduced, the stress term for the finite region is, correspondingly, increased. Moreover, as the former is reduced, the exponent for the finite stress term increases, the magnitude of which always remains less than 1. At the same time the constant b increases with decreasing endurance limit.

To the best of the author's knowledge, no experimenter has written the general mathematical law for the S-N curve for both the finite and the infinite regions. These experiments indicate it to be of the general form $S = S_e + bN^r$. Eden, Rose and Cunningham (7), from the

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[3] For detailed mathematical derivation of these and subsequent equations, see author's original thesis entitled "A Study of Fatigue of Steels Due to Repeated Applications of Mechanical Stresses In the Finite Region," The Johns Hopkins University, June, 1950.

S-N curves obtained from their experiments—made on a 1 million reversal basis—inferred a law of the form

$$S = CN^{a}$$

where:

$S = \frac{1}{2}$ range of stress,

N = number of reversals to fracture, and

C = constant.

By plotting log S against log N, a straight line results. If this law were to hold indefinitely, then an extension of the straight line would cut the N axis at a value of zero stress. From this it would be concluded that a metal would fail at all stresses if the number of stress reversals was large enough. This exponential law holds only within the scope of their experiments, which, as already mentioned, was 1,000,000 stress reversals. Basquin (8), in 1910, made a careful study of fatigue testing data in the infinite range. He indicated that the exponential law fitted all the test results examined up to 10,000,000 reversals, but from there on seems to vary from the test results obtained. Lengthy endurance tests up to 200,000,000 reversals indicate that endurance limits do exist for steels.

Examination of the actual equations obtained in the previous section for the S-N curves indicate that over the entire elastic range these equations are valid. In the infinite region as the number of stress reversals is increased, the second term in the equation decreases and the two terms of the equation together approach closer and closer to the actual endurance limit obtained by experiment. For example, the equation for the large radius type of specimen for steel No. 3, that is,

$$S = 65{,}000 + 1{,}510{,}000\, N^{-0.3610}$$

gives the following results:

Number of Cycles	Stress Calculated from Equation, psi	Stress Obtained from Curves, psi	Per cent Error
10 000	122 000	130 000	−6.1
100 000	88 000	92 000	−3.2
1 000 000	74 600	71 000	+4.3
10 000 000	68 000	65 000	+4.6
100 000 000	67 000	65 000	+3.08

Due to the fact that each of the equations obtained in the previous section was based on data from 15 to 20 test specimens, the range of error was ±6 per cent. If a larger number of test specimens had been used, then the range would have been decreased by several per cent. Again, too, there was scatter in the results which would affect the equations slightly. The constants, S_e, b, and r will vary for each type of specimen for one steel and, in turn, for each different steel. They will also vary for the type of straining action used, namely, bending, tension-compression, or torsion.

Variations of the fatigue strength reduction factor, k_f, with the number of stress reversals is demonstrated by the curves in Figs. 6, 7, 8, and 9 for the steels studied. These curves indicate that as the stress magnitude is increased, this factor decreases and approaches 1 as a lower limit in the plastic region. Within the high stress part of the finite region, it is evident, therefore, that the shape of the discontinuity does not have very great effect on the stress.

In the lower stress region, on the other hand, k_f reaches an upper limit, between 2 and 5 million stress reversals depending on the type of notched specimen and the material used. Highest values of k_f were obtained for 45-deg V-notch specimens, followed by 90-deg V-notch, square shoulder, and small radius specimens. The values of k_f obtained in the infinite region are less than the theoretical stress concentration factors, k, obtained by mathematical or photoelastic means.

The equation found to fit best the experimental data for the fatigue strength notch factor statistically over the entire finite and infinite regions is of the general form:

$$k_N = tu^{vN} \tag{1}$$

where:

k_N = the fatigue strength notch factor at N cycles of repeated stress,

t, u, v = parameters to be determined mathematically, and

N = cycles of repeated stress.

When the parameters, t, u, and v are determined, the empirical equations obtained for the fatigue strength reduction factor k_N, in terms of the cycles of repeated stress, N, are listed as follows:

STEEL NO. 1

Square shoulder:
$$k_N = 1.33\ (1.58)^{-0.681N}$$
90-deg V-notch:
$$k_N = 1.40\ (1.69)^{-0.716N}$$
45-deg V-notch:
$$k_N = 1.43\ (1.71)^{-0.732N}$$

STEEL NO. 2

Small radius:
$$k_N = 1.26\ (1.49)^{-0.653N}$$
Square shoulder:
$$k_N = 1.67\ (1.98)^{-0.791N}$$
90-deg V-notch:
$$k_N = 1.90\ (2.25)^{-0.872N}$$

STEEL NO. 3

Small radius:
$$k_N = 1.41\ (1.69)^{-0.721N}$$
Square shoulder:
$$k_N = 1.70\ (2.07)^{-0.822N}$$
45-deg V-notch:
$$k_N = 2.25\ (2.85)^{-0.995N}$$

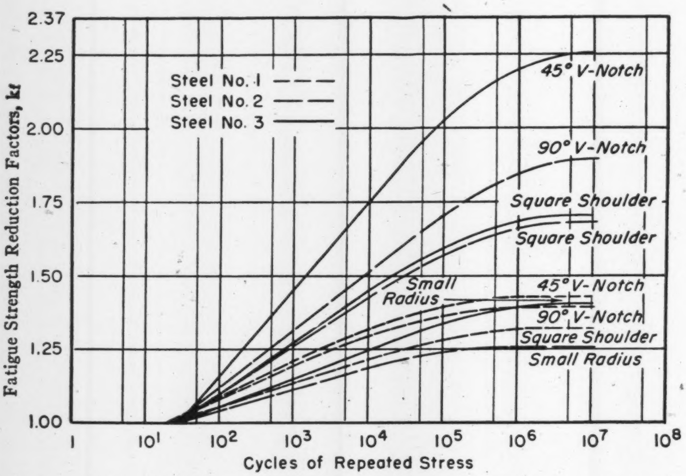


FIG. 9.—Variation of k_f with Number of Cycles of Repeated Stress for Three Cr, Ni, Mo, V Steels.

Data calculated from the empirical equations for the fatigue strength reduction factor over the entire k_N-N plane approximate fairly well the data obtained from the experiments. In the finite region, the percentage error of k_N is much higher than in the infinite region. The reason for this is that the fatigue strength reduction factor k_N at most, varies slightly less than $1\frac{1}{2}$ units, while the value of N varies from about 40 to approximately 5,000,000 cycles. Thus, when a small value of N is substituted into the expression $k_N - tu^{vN}$, the error for k_N may run as high as 20 per cent;

while if a large value of N is substituted into the equation, the error drops to less than 2 per cent.

Variation of the fatigue strength reduction factor, k_f, with the mechanical properties of the steels studied shows that this factor increased with increase in the tensile and yield strengths, and also for the impact resistance. The increase in the finite region was not as large as in the infinite region. The factor appears to approach a value of 1 for tensile and yield strengths of 115,000 and 90,000 psi, respectively, and at an impact resistance approaching near zero.

The fatigue strength reduction factors obtained in the infinite region agree remarkably well with the values obtained by other experimenters for the different physical properties and notch angles used. Tables IV and V list the theoretical, and fatigue strength reduction factors for both the finite and infinite regions. The agreement between theory and test is remarkably good considering that the values of k_f for steels Nos. 2 and 3 did not vary more than 50 to 75 per cent from the values of k determined mathematically. The latter k, in turn, is based on only the relative depth of the notch d/B and the ratio r/B, and does not take into consideration the physical and metallurgical properties of the material itself. On the other hand, k_f is based on the physical and metallurgical properties since it is obtained experimentally.

It was found, in general, that as the tensile or yield strength and the impact resistance of a material is increased, the slopes of the fatigue curves in the finite region for both notched and unnotched specimens are increased correspondingly. For example, the slopes decrease in the following order: 45-deg V-notch specimens, followed by 90-deg V-notch, square shoulder, small radius, and large radius specimens. Based on the tensile strength, for example, an increase from 130,000 to 180,000 psi increases the slope of the S-N curve for small-radius type specimens by approximately 18 per cent, while for the 45-deg V-notch specimens the increase is approximately 47 per cent. If, instead of basing the slope increase of S-N curves on the tensile strength, the yield strength is used, the slopes of the S-N curves for values between 100,000 and 150,000 psi increase from 16 per cent for small radius specimens to 39 per cent for 45-deg V-notch specimens. The same general range of slope increase is obtained for the impact resistance between 5 and 20 ft-lb. For the small-radius type of specimen, moreover, the increase in the slope of the S-N curve is approximately 12 per cent, while for the 45-deg V-notch units it is roughly 42 per cent.

Significance of this is that increases in any one of the three considered physical properties decreases the life of the notched specimens correspondingly, to a degree dependent upon the stress level at which the operation is taking place. For example, on considering the S-N curves of Fig. 5 for the square-shoulder type at a stress level of 100,000 psi, an increase in the impact resistance from 5 to 25 ft-lb for steels Nos. 1 and 2, respectively, reduces the life from 6000 to 4400 stress reversals or approximately 27 per cent. For 80,000 psi, the life would be decreased by 41 per cent or from 22,000 to 13,000 reversals.

The present experiments were run at 600 rpm in order to reduce temperature effects and at the same time to facilitate loading of the testing machine. If a higher speed had been used, it is probable that the S-N curves would have been shifted slightly to the right for unnotched specimens and to the left for notched specimens. This would cause a decrease in finite life due to the heating of the test unit with increase in speed of stress reversals. Examination of the specimens during test indicated that there was no heating effect produced at 600 rpm.

The S-N curves for these types of specimens in the finite region is shifted either to the left or to the right, depending on whether or not the root base radius was decreased or increased in magnitude, respectively. In the infinite regions, for the same notched specimens, these S-N curves are either raised or lowered, depending on whether or not the root base radius is increased or decreased, respectively. The extent to which these curves are shifted can be ascertained only through further investigations of an experimental nature, using the same steels.

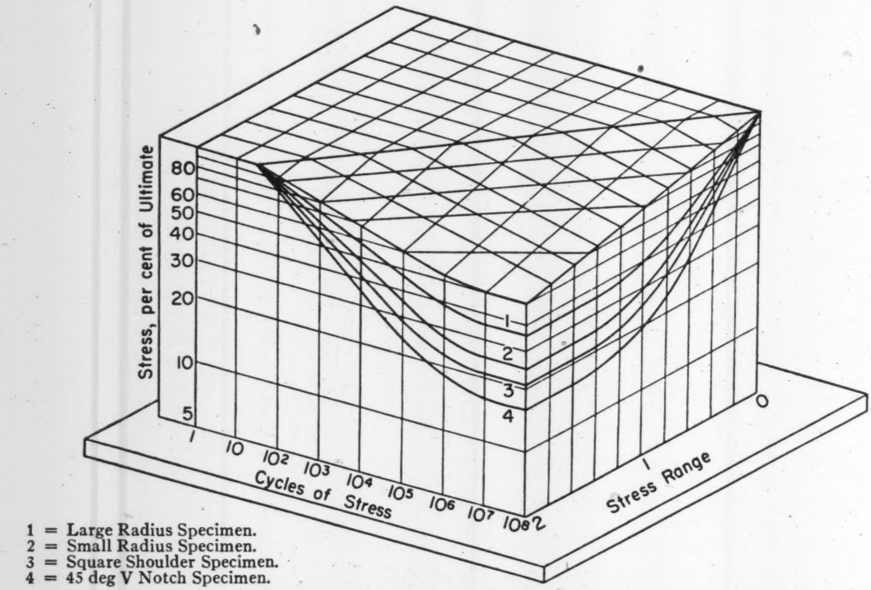
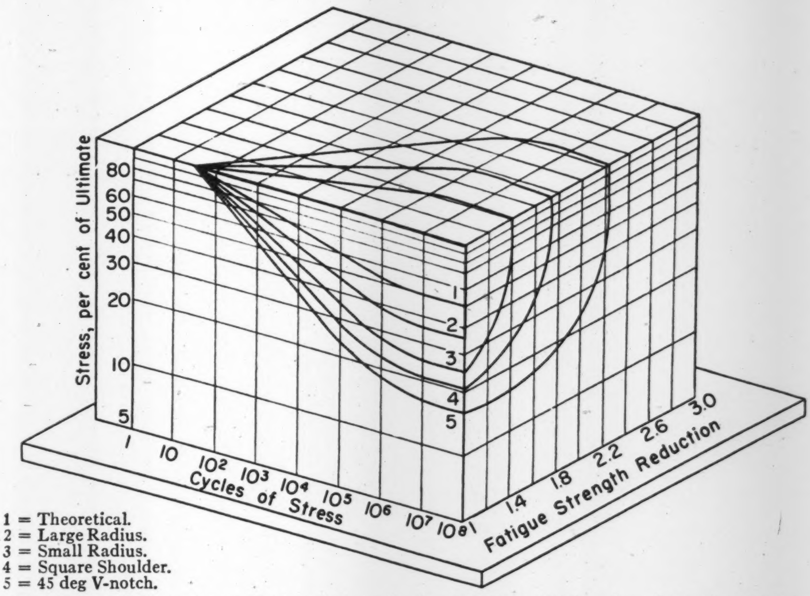


FIG. 10.—Three Dimensional Fatigue Diagram for Steel No. 3 Showing the Effect of Range of Stress on the Slope of the Fatigue Curve.

Some conception of how the S-N curves are shifted due to the variation of the notch-base radius can be obtained by examining the curves for the small radius specimens with the ones for the square shoulder or 45-deg or 90-deg V-notch. For example, consider steel No. 3. Here one sees that the S-N curve for the small radius type is much higher in both the finite and infinite range compared to the ones for the square-shoulder and 45-deg V-notch type; or an increase in the root-base radius from 0.01 in. (square shoulder) to 0.05 in. (small radius) for example, at 100,000 psi stress level increases the finite life from 6000 to 12,000 reversals or by approximately 100 per cent.

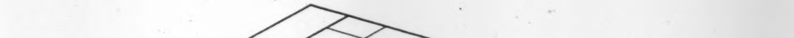
Regardless of the direction in which the curves are shifted, it is quite evident that they will still converge to the same point in the high stress range about 20 to 40 cycles depending on the material.

Figure 10 represents a three dimensional diagram on logarithmic coordinates for steel No. 3. The vertical scale of this diagram represents stress in per cent of the ultimate, the horizontal scale on the forward side the



1 = Theoretical.
2 = Large Radius.
3 = Small Radius.
4 = Square Shoulder.
5 = 45 deg V-notch.

FIG. 11.—Three Dimensional Fatigue Diagram for Steel No. 3 Showing the Effect of Stress Concentration Factor on the Slope of the *S-N* Curves.



1 = Small Radius.
2 = Square Shoulder.
3 = 45 deg V-notch.

FIG. 12.—Three Dimensional Fatigue Diagram for Steel No. 3 Showing the Effect of Range of Stress on Slope of the k_N-N Curves.

stress reversals, and the horizontal depth scale the stress range, which range is defined as (9)

$$\text{Stress range} = 1 - \frac{\text{Stress Minimum}}{\text{Stress Maximum}}$$

On the forward face are represented the *S-N* curves (1) for steel No. 3 for complete reversal of stress (equal tension and compression). The back face, on the other hand, represents an *S-N* curve for a stress range of zero. A section half way between these two planes would represent *S-N* curves for a stress range of 1 (zero stress to maximum stress in either tension or compression). The upper surface indicates the theoretical surface that should be obtained for unnotched specimens. Due to variations in crystalline structure, surface finish, physical properties, and other factors, this theoretical value of 50 per cent is rarely achieved with unnotched specimens.

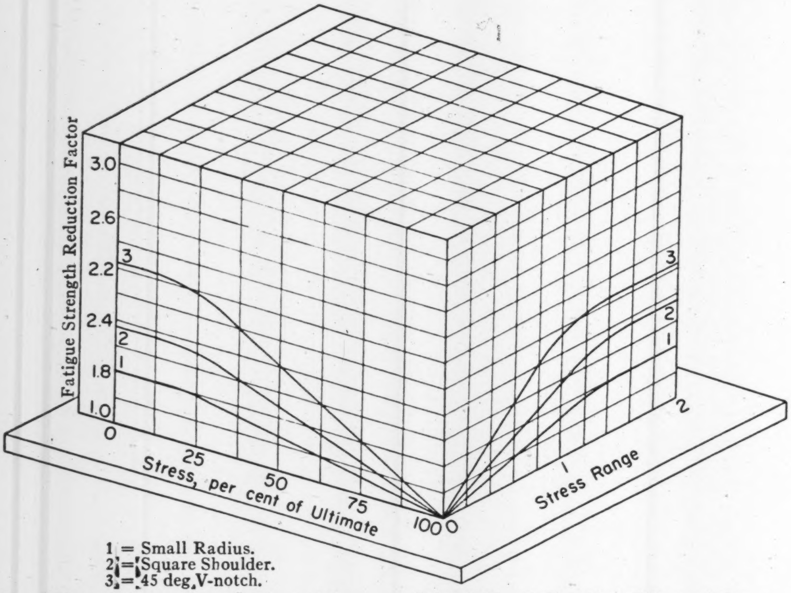


FIG. 13.—Three Dimensional Fatigue Diagram of Steel No. 3 Showing Effect of Range of Stress on the Stress Concentration Factor Curves.

The scale for stress range was selected so that 2 represents complete reversal of stress (maximum in tension and compression); 1, on the other hand, represents from zero stress to maximum in tension and compression; 0 indicates no change in stress value. The forward face was plotted from the experimental data obtained from the present experiments; the stress range face was approximated from the above equation. This face shows that the curves also converge to a point at a stress range of zero and the maximum value of stress.

Figure 11 illustrates the effect of the fatigue strength reduction factor on the slope of the *S-N* curves in three dimensions for steel No. 3. It shows that as the severity of the notch is increased, the slope of the *S-N* curve is increased correspondingly, the greatest effect being obtained for the 45-deg V-notch.

Figure 12 shows the effect of range of stress on the fatigue strength reduction factor curves for the same steel. For a complete reversal of stresses; namely, equal tension and compression for a 100 per cent ultimate stress load, the value of the factor is 1. As the ultimate stress is decreased, the factor increases for the particular range of equal tension and compression stresses until the values of the factors at the endurance limit are reached. For stress ranges less than complete reversal, smaller values are obtained from the factors, until at a stress range of zero and an ultimate stress of 100 per cent, the factor achieves a theoretical value of unity. This is what is to be expected because if there is no change in stress value, there can be no stress concentration.

Figure 13 points out the effect of range of stress on the slopes of the R_N-N curves for steel No. 3 in that the greatest slopes are obtained for the most critically notched specimens for a complete reversal of stress load. As the range of stress approaches zero, the slopes of the curves for the various types of notched specimens tend to approach each other and do so at a value of zero.

These three dimensional diagrams can only be proved by additional experiments, which would be very costly because of the number of specimens and special apparatus required. They are put forth solely to indicate how the S-N and R_N-N curves possibly vary with stress range.

Acknowledgment:

The author takes this opportunity to thank Dr. A. G. Christie, of the Johns Hopkins University, under whose capable guidance this work was done, and Joseph Gray Jackson, Esquire, for his assistance in suggesting the problem and making it possible to obtain the specimens for carrying out this investigation.

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DISCUSSION

Mr. R. E. Peterson.[1]—Some of the *S-N* curves of Mr. Finch's paper seem to be straight lines intersecting at a point. Others seem to bend over. Is there an explanation for that?

Mr. W. G. Finch (*author*).—The only explanation that I have for this is that possibly plastic flow of the metal was taking place.

It will be noted that the *S-N* curves for the square shoulder types of specimens tended to bend off to the left, but if these same curves are projected upwardly, they tend to converge to the same point that the *S-N* curves for the V-notch types of specimens radiated from.

Mr. T. J. Dolan.[2]—I was interested in the author's curves which show a decrease in the strength reduction factor at low fatigue life, that is, low numbers of cycles of stress. The general impression in the minds of many engineers has been that this is the case for most metals. For the three steels investigated by the author, the effectiveness of the notch in reducing the strength was greatly decreased at lower numbers of cycles.

However, this trend is not necessarily true for all metals. In fact, recently, we completed a series of tests on alpha brass in which a study was made of the effects of grain size on notch-sensitivity. We did not complete the data on these six different groups of brass back to as low a number of cycles as the author, but found that over the range from 10,000 to 100,000,000 cycles the ratio of unnotched fatigue strength to notched fatigue strength was nearly *constant* (within the limits of experimental error). It is hoped that these data will soon be published[3] and may be of interest in exhibiting a slightly different type of behavior from that presented in the paper. Evidently the complexities of the fatigue phenomenon are so great that one can obtain widely different kinds of behavior by altering the metal or its test conditions.

Mr. M. J. Manjoine.[4]—In the author's curve for the strength of the notched and unnotched specimens it appears that the curve for the notched bars crosses that for the unnotched bars for a low number of cycles. This is a notch strengthening effect. Does the author have any data in this region or have the curves been extrapolated to a low number of cycles?

Mr. Finch (*author's closure*).—As I pointed out earlier, the *S-N* curves for the square shoulder and large radius types of specimens were projected upwardly. The results for the V-notch and square types of specimens were then compared with the results for the large radius types of specimens in order to obtain the fatigue strength reduction factors over the range of 40 to 50 cycles of repeated stress in the high stress region to millions of cycles of repeated stress in the low stress region near the endurance limit of the steels studied.

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[2] Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[3] To be presented at the 1953 Annual Meeting of the Society.

[4] Westinghouse Electric Co., East Pittsburgh, Pa.

THE ANISOTROPY OF THE FATIGUE PROPERTIES OF SAE 4340 STEEL FORGINGS*[1]

BY J. T. RANSOM[2] AND R. F. MEHL[3]

SYNOPSIS

The anisotropy of fatigue properties in steel forgings was studied statistically using SAE 4340 from heats which showed both high and low transverse average tensile reduction of area. The average transverse endurance limit was found to be 84 per cent of the average longitudinal endurance limit in the high RAT (reduction of area transverse) steel, while the ratio was only 68 per cent in the low RAT steel. Life to failure at the higher stresses was similarly anisotropic with a similar dependence on quality as judged by RAT. It was concluded that the anisotropy of fatigue properties, like the anisotropy in reduction of area, is determined in a large part by the presence of fragmented stringer type inclusions.

The Metals Research Laboratory of Carnegie Institute of Technology has carried out an extensive series of researches on the tensile and impact properties of wrought steels (1)[4] with detailed attention to anisotropy.[5] This paper gives the results of a study of the effect of the direction of measurement upon the fatigue properties of SAE 4340 steel forgings. It was desired to find out if the fatigue properties were anisotropic and if the degree of this anisotropy in fatigue properties was related to the amount of anisotropy in the tensile reduction of area.

The fact that the fatigue strength transverse to the forging fiber may be appreciably less than the fatigue strength parallel to the fiber, as is the ductility, has been largely overlooked. In many forged machine parts, maximum stresses occur in a transverse direction. Crankshafts, connecting rods, and gun tubes are examples. Nevertheless fatigue properties are almost universally measured in the longitudinal direction with the tacit assumption that they are isotropic or nearly so.

LITERATURE REVIEW

The possibility that the longitudinal and transverse fatigue strengths might be different was mentioned by Howe (2) in 1916. McAdam (3) appears to have been the first to make an experimental study. His results were inconclusive due to the heterogeneity of microstructure in the large steel shafts which he studied and due to using too few specimens to reveal clearly an anisotropy. Aitchison (4) remarked that the fatigue strength

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[*] Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] This paper represents part of a thesis submitted by J. T. Ransom in partial fulfillment of requirements for the degree of Doctor of Science to the Graduate Committee of the Carnegie Institute of Technology.

[2] Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del. Formerly Instructor and Graduate Student, Department of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

[3] Professor and Head, Department of Metallurgical Engineering, and Director, Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa.

[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 786.

[5] A property is anisotropic when its magnitude depends upon the direction in which the property is measured.

ought to be related in part to the ductility properties and therefore ought to show anisotropy. However, in a subsequent investigation of several steels and irons, Aitchison and Johnson (5) found little or no anisotropy. The details of the testing were not described sufficiently to permit appraisal in light of present knowledge, so that an explanation of this result cannot be given. Junger (6) found only a negligible anisotropy in duralumin plates. Hensel and Hengstenberg (7) and Moore and Wishart (8) studied the anisotropy of fatigue strengths in wrought iron and found the fatigue and tensile properties very erratic. Mailander (9) found a strong anisotropy in heat treatable steel; but the details of the experiments were not given and the reliability of his conclusions cannot be evaluated. Von Schmidt (10) studied the effect of forging reduction on the anisotropy of several properties including the fatigue strength and claimed to find a 15 per

TABLE I.—AVERAGE TENSILE PROPERTIES OF TEST TUBES.

Tube	Heat	Yield Strength, 0.1 per cent offset, psi		Tensile Strength, psi		Reduction of Area, per cent		Number of Tension Tests	
		Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
No. 46	No. 15254	107 000	107 000	125 000	125 000	66.2	22.8	4	5
No. 51	No 15254	107 000	107 000	125 000	125 000	66.6	27.6	40	50
No 142	No. 15620	106 000	105 000	123 000	123 000	68.6	57.0	40	50
No. 143	No. 15620	106 000	106 000	122 000	122 000	63.5	58.4	4	4

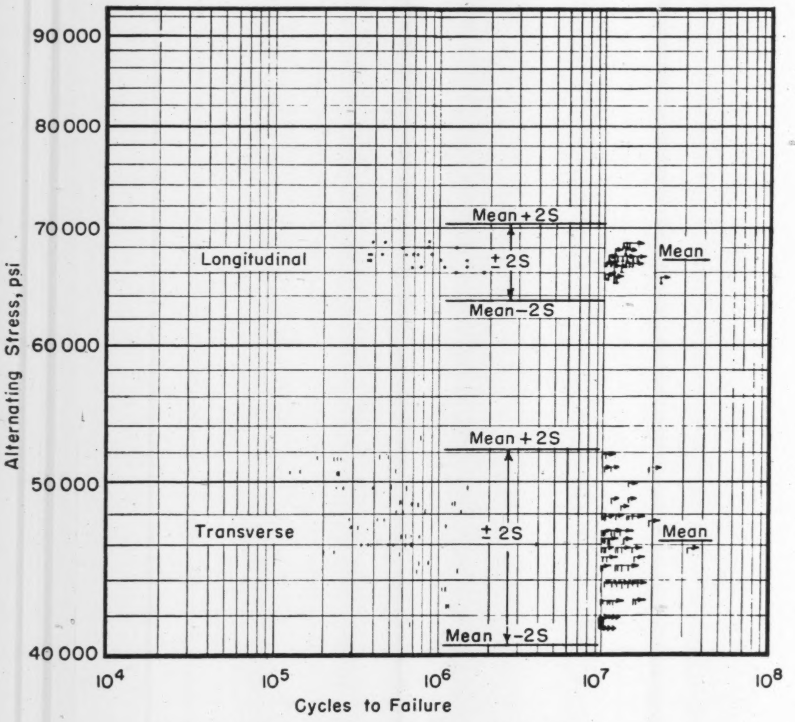

FIG. 1.—Endurance Limit Data, Tube No. 46.

cent decrease in transverse endurance limit at higher forging reductions. However, considering the large scatter in the results, it is obvious that Von Schmidt did not test a sufficient number of specimens to justify his conclusions on a statistical basis.

Cornelius and Krainer (**11**) studied anisotropy in a heat-treated steel and observed a 45 per cent lower fatigue strength in the transverse direction. However, this was probably due to microstructural differences between longitudinal and transverse specimens. Von Rossing (**12**) studied specimens cut from five steel forgings such as crankshafts and connecting rods. He observed up to a 29 per cent difference of endurance limit in specimens of various orientations, but the true grain direction was difficult to analyze. Krainer (**13**) studied the effect of various forging reductions on the anisotropy of fatigue strength for a single large steel rotor forging. His results were confused by strength and microstructural variations among the groups of specimens. Unkel (**14**) was not able to reach any conclusion about anisotropy of fatigue strength in aluminum alloys because of large experimental variation. Morris (**15**) studied anisotropy of fatigue strength in mild steel, with and without sulfur additions.

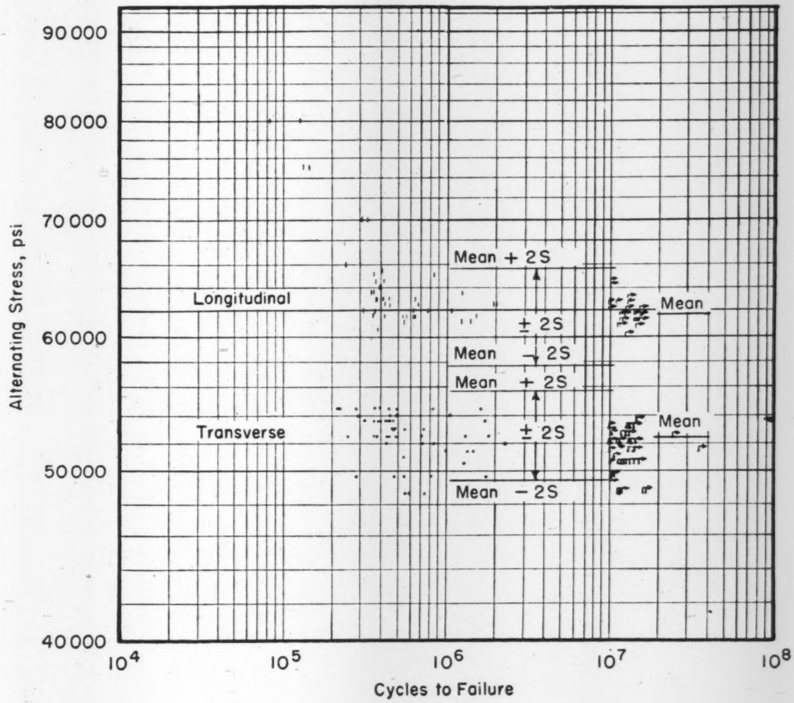

FIG. 2.—Endurance Limit Data, Tube No. 143.

TABLE II.—SUMMARY OF MEAN ENDURANCE LIMITS.

Tube	Test Direction	Endurance Limit, psi	Tensile Strength, psi	Endurance Ratio
No. 46	Longitudinal	67 040	125 000	0.54
No. 46	Transverse	46 270	124 800	0.37
No. 143	Longitudinal	61 750	122 000	0.51
No. 143	Transverse	52 460	122 000	0.43

TABLE III.—ANISOTROPY IN FATIGUE AND DUCTILITY.

	Tube No. 46	Tube No. 143
Ratio $\dfrac{\text{Mean transverse endurance limit}}{\text{Mean longitudinal endurance limit}}$	0.68	0.84
Ratio $\dfrac{\text{Average RAT}}{\text{Average RAL}}$	0.34	0.92

He found no anisotropy in this soft steel.

The literature is therefore inconclusive on the existence of isotropy or anisotropy in the fatigue properties of forgings in general. For alloy steels some investigators have found a pronounced dependence of fatigue properties upon direction of testing, while others have found little or none. In general, these researches were inconclusive for one or more reasons: lack of control of specimen—that is, transverse specimens of microstructure or strength level different from the longitudinal—differences in residual stresses between longitudinal and transverse specimens, or uncertain results arising from a large scatter in data and insufficient number of specimens. The literature thus offers no clear cut evidence.

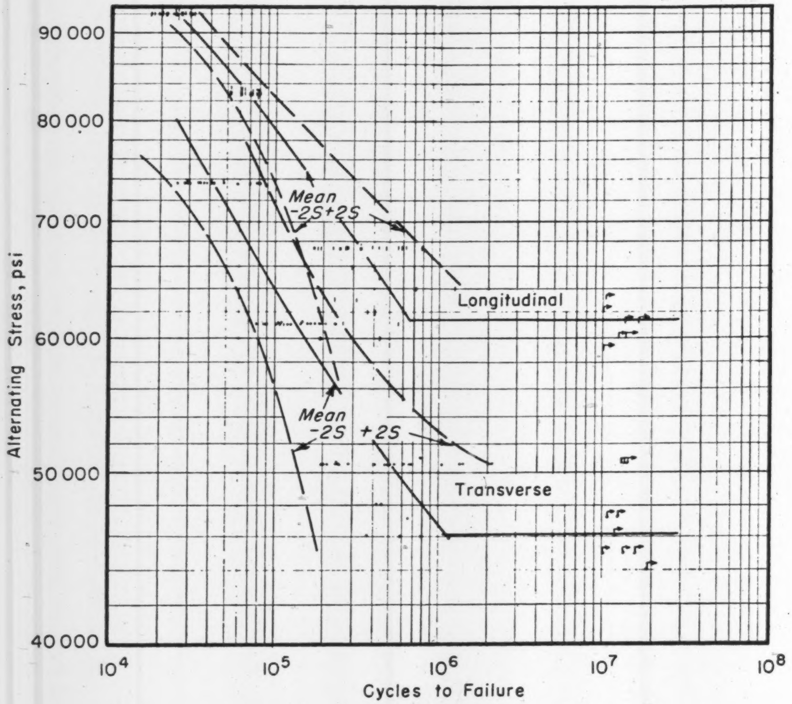

FIG. 3.—Fracture Data, Tube No. 51.

EXPERIMENTAL

In the present work it is believed that the experimental uncertainties noted above were avoided. The materials studied were 40 mm gun tubes of SAE 4340 analysis. Wells and Mehl (1) had shown that when these tubes come from a properly controlled production practice, the only significant difference between tubes is in the RAT (reduction of area transverse) quality. Other tensile properties are essentially alike among tubes and in the longitudinal and transverse directions within tubes. Thus it was possible to select a pair of tubes from each of two different heats such that the tubes from one heat had high average RAT while the tubes from the second heat had low average RAT. The average yield and tensile strengths in the longitudinal and transverse directions in all tubes were essentially the same; the average reduction in area in the longitudinal direction (RAL) was essentially the same for all tubes; and for one pair the average RAT approached the average RAL values. The tubes were reduced about 20 to 1 in forging from the ingot, normalized at 1700 F, oil quenched from 1525 F, and drawn 10 hr at 1170 F. The complete tensile data for the tubes are given in Table I.

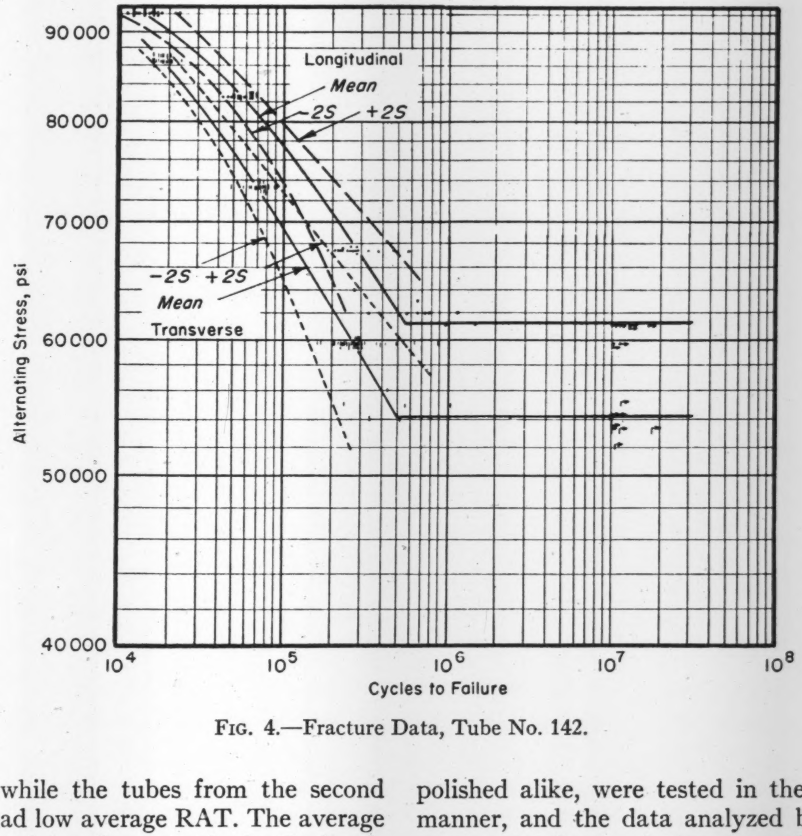

FIG. 4.—Fracture Data, Tube No. 142.

Extreme care was taken so that longitudinal and transverse specimens were taken from the same midwall position in the forgings, were machined and polished alike, were tested in the same manner, and the data analyzed by the same procedures. A large number of specimens were used so that statistical analyses could show that the results were statistically significant. The complete details of the preparation of specimens, the R. R. Moore testing equipment and procedure, and the statistical treatments have been given in a companion paper (16).

FIG. 5.—Typical Inclusion Field, Heat No. 15254 (× 100).

FIG. 6.—Typical Inclusion Field, Heat No. 15620 (× 100).

RESULTS

The data obtained by exhaustive studies of the endurance limit ranges for Tubes No. 46 and No. 143 have been plotted in S-N form in Figs. 1 and 2. The estimated mean endurance limits[6] have been indicated. The significance of the $\pm 2s$ figures is discussed elsewhere (16). The estimates of the mean endurance limits, as obtained by the staircase procedure, together with the tensile strengths and endurance ratios have been summarized in Table II. It is evident that there was a large anisotropy in mean endurance limit, even for the high quality steel, No. 143. This anisotropy has been revealed more clearly in Table III where ratios of the average endurance limits and ratios of the average tensile reduction of area in transverse and longitudinal direction have been given. In the steel which showed very little anisotropy of ductility, the transverse endurance limit was 84 per cent of the longitudinal; in the steel of pronounced anisotropy in ductility, the transverse endurance limit dropped to only 68 per cent of the longitudinal.

FIG. 7.—Occasional Inclusion Field, Heat No. 15254 (× 100).

Figures 3 and 4 present the data which were obtained in the study of the anisotropy at stresses above the endurance limit range for Tubes No. 51 and No. 142. The solid lines have been drawn through the mean life (in logarithmic form) of each group of specimens tested at a given stress level. The dashed lines indicate mean $\pm 2s$ limits, the significance of which is discussed elsewhere (16). It is evident that life to failure at high stresses is anisotropic in a manner similar to the anisotropy of endurance limit.

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[6] Mean endurance limit was defined as the stress at which 50 per cent of all specimens would fail and 50 per cent would remain unbroken after ten million cycles and presumably indefinitely.

DISCUSSION

It is likely that the same factor or factors which cause anisotropy in the reduction of area property also cause the anisotropy in fatigue properties. Both properties are determined by the initiation of a crack and therefore depend upon local characteristics rather than average characteristics of the steel (in contrast to the tensile strength, for example).

Wells and Mehl (1) and later Welchner and Hildorf (17) have shown that inclusions are a major cause of the anisotropy in reduction of area of this type of steel product. These investigators concluded that the type of inclusion content was more important in determining the transverse ductility of this grade of steel than the total amount of inclusions.

In the present investigation the inclusions were studied for a large number of specimens of the two heats. Photomicrographs of typical areas have been given in Figs. 5 and 6 for the low RAT and high RAT tubes respectively. The total inclusion content for tubes from each heat was nearly the same and at a fairly low value. However, the heat of low RAT quality contained occasional areas with the fragmented stringer type inclusion as shown in Fig. 7.

Although the present data were obtained on but two heats of steel, it seems likely that the conclusions of Wells and Mehl, and Welchner and Hildorf concerning inclusion effects on transverse ductility will apply at least in a qualitative fashion to the effects of inclusions on transverse fatigue properties. If additional evidence to support this generalization can be obtained by other investigators, the transverse tensile reduction of area could be used as a quality index for transverse fatigue properties with considerable saving in time and expense.

Acknowledgment:

The authors wish to acknowledge the assistance of Cyril Wells and Paul Busby in the selection of the materials for this investigation and to express appreciation to them for many helpful and stimulating discussions.

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DISCUSSION

Mr. H. J. Grover.[1]—In many cases of actual service and also in cases where notches are a part of the picture, combined stresses inevitably occur. What should one do in such a case when there is some great difference between the longitudinal and transverse endurance limits? I wonder if Mr. Ransom has any suggestions about this.

Mr. W. T. Lankford.[2]—I notice that the longitudinal endurance limit of the "low-quality" steel was 67,000 psi as compared with 61,800 psi for the "high-quality" steel, whereas the tensile strengths differed by only 3000 psi; that is, the tensile strength of the "low-quality" steel was 125,000 psi as compared with 122,000 psi for the "high-quality" steel. Will the authors comment on the observed difference in the level of the longitudinal endurance limits relative to the difference in tensile strengths?

Mr. T. J. Dolan.[3]—The authors intimated that nonmetallic inclusions and stringers seem to be the logical source of anisotropy in steels. This raises the question in my mind whether the anisotropy is attributable entirely to the presence of the nonmetallic inclusions as stress-raisers or whether there may also be what might be classified as a microscopic crack associated with the inclusions.

During the war, we had some experience with gun-tube forgings in which there were what were variously called flakes, shatter cracks, or "fish eyes," etc. These often were found associated with a nonmetallic inclusion as a nucleus and could be seen only with the aid of a microscope.

The presence of an actual microscopic crack of this nature would lead one to expect vastly reduced fatigue strengths when tested in the transverse direction. Since the authors' specimens were also cut from tubes, I am wondering whether there is a possibility of such voids having existed in association with the nonmetallic inclusions or whether the anisotropy can be attributed to the presence of the nonmetallic stringers alone.

Certainly it does seem possible that if the specimen is stressed in a direction for which the elongated stringer would tend to produce the greatest stress-raising effect in the material, one might expect a greater reduction in fatigue strength than when the stress is oriented in other directions. However, the reported reduction of the transverse fatigue strength to two-thirds of the value in the longitudinal direction seems to be a rather drastic effect. This is larger than has been experienced in past tests and it is a rather important strength reduction if we are to expect this much variation in a common commercially rolled product.

Mr. Joseph Marin.[4]—I should like to report briefly on some results that we obtained, which supplement the results given in the paper. For 14S-T4 aluminum alloy, we found that the fatigue strength in the transverse direction was about 65 per cent of that in the longitudinal direction.

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[1] Battelle Memorial Institute, Columbus, Ohio.

[2] Research Associate, Research and Development Div., United States Steel Co., Pittsburgh, Pa.

[3] Head, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[4] Professor of Engineering Mechanics, The Pennsylvania State College, State College, Pa.

MR. PETER R. KOSTING.[5]—In a forging of high RAT quality, the ratio of transverse endurance limit to longitudinal endurance limit was observed to be around 0.86. This value is similar to the one reported by the authors.

Information about finite life of specimens is of interest to engineers. For this reason ratios in the region of finite life would be helpful.

No reference in this work has been made to the toughness of the material. This is also an important factor in fatigue.

CHAIRMAN G. R. GOHN.[6]—I should like to point out that in testing nonferrous metals with properties derived from coldworking rather than heat treatment, you usually will find anisotropy or an anisotropic effect, but the mechanical properties are improved when specimens are tested in the transverse rather than the longitudinal direction. Generalization on the basis of Mr. Ransom's data cannot be made.

MR. J. T. RANSOM (*author's closure*).—With regard to Mr. Grover's query about the combined stress problem with anisotropic materials, I cannot give an answer yet. We have conducted considerable research on the problem at the du Pont Company but as yet I do not believe the results warrant generalizations. I hope that we can publish this work at the next meeting of the ASTM.

I have no answer for Mr. Lankford's question about the differences in the longitudinal endurance limits. There is no question that the differences are real but why they are so large is indeed puzzling.

In reply to Mr. Dolan's question, I cannot say for the steel reported here whether it is the inclusion itself or a microscopic crack associated with the inclusion that is responsible for the anisotropy. In subsequent work done at the du Pont Company I have been able to show much more clearly that the fatigue failures in transverse bending specimens and in all torsion specimens originate at inclusions, at least in all steels which we have studied to date. This has been established conclusively by stopping the fatigue tests when the fatigue cracks were only a few thousandths of an inch in length so that the origin of the failure was clearly revealed. In these steels I have never found the type of microcracks to which Mr. Dolan refers.

Mr. Dolan is surprised that the strength reduction factor is so high in the transverse direction. I might say that at the du Pont Company I have tested some SAE 4340 forgings which would be considered of high quality by usual standards. In repeated bending fatigue tests the transverse endurance limit has been found to be as low as 50 per cent of the longitudinal. I might also mention some work on vacuum-melted steel which we hope to report next year. This vacuum-melted steel was an SAE 4340 composition but devoid of any but the most minute inclusions. Fatigue tests show that for this steel the transverse endurance limit is nearly as high as the longitudinal.

It is gratifying to have the confirmation of the anisotropy supplied by Messrs. Marin and Kosting. With regard to anisotropy ratios in the finite life region, while this would be valuable information when obtained in simulated service tests, I would not know how to use this information when obtained on, say, R. R. Moore machines. Translating finite life data into service is even more difficult than translating endurance limit data into service because one has to contend with the additional factors which affect the rate of crack propagation.

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[5] Watertown Arsenal, Watertown, Mass.

[6] Supervisor, Creep and Fatigue Laboratories, Bell Telephone Laboratories, Inc., New York, N. Y.

I should like to thank Mr. Gohn for his remarks about the dangers of generalization. Certainly in materials, such as cold-worked non-ferrous metals, where different tensile strengths are found in different dierctions, one could expect different fatigue strengths. But even, as in the work reported here, when there is no anisotropy in tensile strength, anisotropy in fatigue strength may exist. And we still have considerable research to do before we can predict the magnitude of the anisotropy to be expected in a given steel.

FATIGUE STRENGTH OF REFRACTALOY 26 AS AFFECTED BY TEMPERATURE, HARDNESS, AND GRAIN SIZE*

By P. R. Toolin[1] and F. C. Hull[1]

Synopsis

Some variables affecting the fatigue strength of a wrought austenitic precipitation-hardened alloy, Refractaloy 26, have been investigated. Results are reported for four levels of titanium content, four different solution treatments, three aging treatments, and four test temperatures. The most important condition for attaining the high 10^8 cycle fatigue strength of 84,000 psi at 1200 F appears to be a fine grain size. At temperatures above 1475 F, a coarse grain size seems advantageous. Hardness before test, as varied by heat treatment or titanium content within the limits investigated, does not correlate with high-temperature fatigue strength in this alloy.

Many precipitation-hardened austenitic alloys are being used in jet engines and other high-temperature applications involving high vibratory stresses. In order to provide designers and metallurgists with basic information on the behavior of these materials under such conditions, a broad survey was undertaken to evaluate the effect on the fatigue strength of such factors as test temperature, hardener content, hardness, solution temperature, grain size, and aging treatment. The preliminary results of this program, although incomplete in many respects, are believed to be of sufficient interest and importance to warrant presentation at this time.

It will be recognized that the above factors are not necessarily independent variables. Hardness, for example, depends principally on the hardener content of the alloy and the aging cycle, but solution temperature and grain size have secondary effects. Hardness changes also occur during the test to an extent depending on the temperature and time. The solution treatment, on the other hand, determines the grain size of the alloy and has a minor effect on aged hardness. These interrelationships must be remembered when one is interpreting the data.

The experimental results reported herein are limited to those obtained on Refractaloy 26, though confirming evidence on some points is available for "K-42-B." The conclusions reached are presumably applicable to other alloys, such as Discaloy, Inconel X, and Nimonic 80, in which titanium is the principal hardener. A parallel program is being carried out to determine the elevated-temperature tensile and rupture characteristics of this same series of heats and treatments, and will be reported later. A few tensile and creep results pertinent to the question of fatigue strength are included here.

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EXPERIMENTAL PROCEDURE

Material:

Refractaloy 26, a wrought austenitic precipitation-hardened alloy, has been used for this investigation. Bar stock was obtained from billets of commercial heats selected to have a wide range of titanium contents. The complete analyses of the heats tested are listed in Table I. In this alloy, aged hardness and properties are usually closely related to the content of the principal hardening agent—titanium. Aluminum, introduced as an impurity in the ferro-titanium, has a slight hardening effect, but the amount present has been kept at a low level. Molybdenum acts mainly as a solid solution strengthener, but, on aging at 1500 F or in service at 1350 to 1500 F, a portion of it may precipitate as a molybdenum compound.

TABLE I.—COMPOSITION OF REFRACTALOY 26 HEATS TESTED.

Heat	Chemical Composition, per cent								
	Nickel	Cobalt	Chromium	Molybdenum	Titanium	Aluminum	Manganese	Silicon	Iron
No. KB-1000....................	37.6	19.1	17.9	3.16	2.52	0.24	0.78	0.93	Balance
No. KB-1024....................	37.1	19.5	17.9	2.80	2.68	0.30	0.76	0.72	Balance
No. R-102......................	37.1	19.6	17.4	3.00	3.10	0.32	0.67	0.72	Balance
No. R-100......................	37.3	19.6	18.1	2.96	3.23	0.36	0.60	0.69	Balance

TABLE II.—SUMMARY OF HARDNESS AND FATIGUE STRENGTH RESULTS.

Heat	Heat Treatment						ASTM Grain Size No.	Average Hardness[a]						Fatigue Strength at 10^8 Cycles, psi		
	Code	Solution Treatment		Aging Time				1200 F		1350 F		1500 F				
		Temp., deg F	Time, min.	1500 F	1350 F	1200 F		Before Test	After 250 hr	Before Test	After 250 hr	Before Test	After 250 hr	1200 F	1350 F	1500 F
No. KB-1024....	1800*C	1800	20		44		8	357	383	364	314			84 000	55 000	
No. R-102....	1800*C	1800	20		44		8+	372	398	373	343	384	292	84 000	60 000	34 000
No. R-100.......	1800*C	1800	20		44		7.5	392	412	386	360			84 000	60 000	
No. R-102.......	1800C	1800	60		44			369	394					76 000		
No. R-102.......	1800*ABD	1800	20	20	20	20	8	356	368					73 000		
No. R-100.......	1800*ABD	1800	20	20	20	20	8							73 000[b]		
No. R-102.......	1950ABD	1950	60	20	20	20	6	360	360					56 000		
No. KB-1000....	2100ABD	2100	60	20	20	20	3	298	318	288[c]	298[c]			53 000	46 000[c]	
No. KB-1024....	2100ABD	2100	60	20	20	20	3	329	330					53 000		
No. R-102.......	2100ABD	2100	60	20	20	20	4	349	362	332[c]	338[c]	342[c]	262[c]	53 000	46 000[c]	37 000[c]
No. KB-1024....	2100C	2100	60		44		3.5	329	370					52 000		
No. R-100.......	1800*C	1800	20		44		7.5							(74 000 at room temp.)		

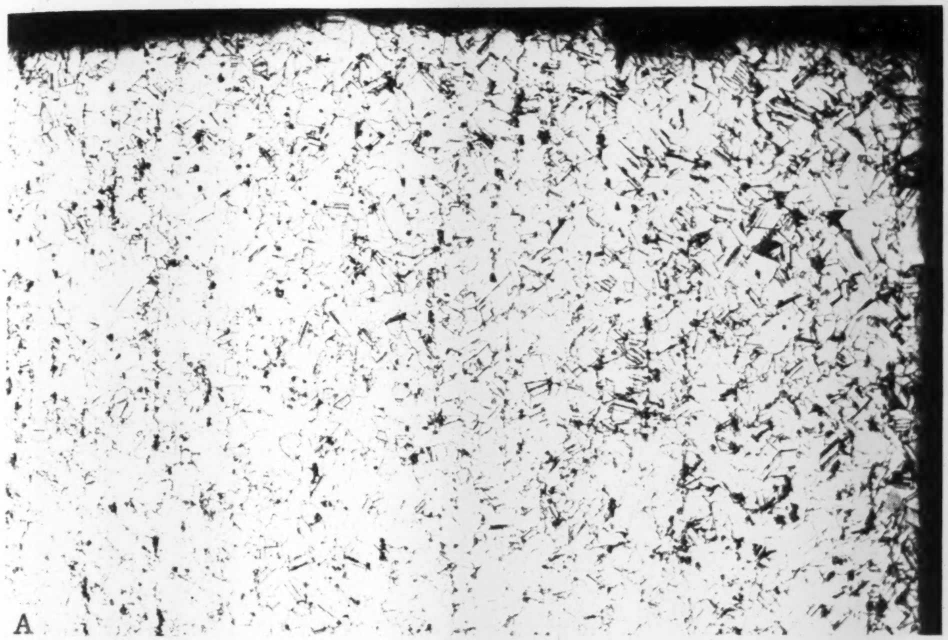
[a] The hardnesses before test were determined on the ends of the specimens, while those at 250 hr were taken on flats made on the side of the clamping section. With this bar stock the before-test hardness on a cross-section is about ten points lower than that on a longitudinal section.

[b] Estimated from one test.

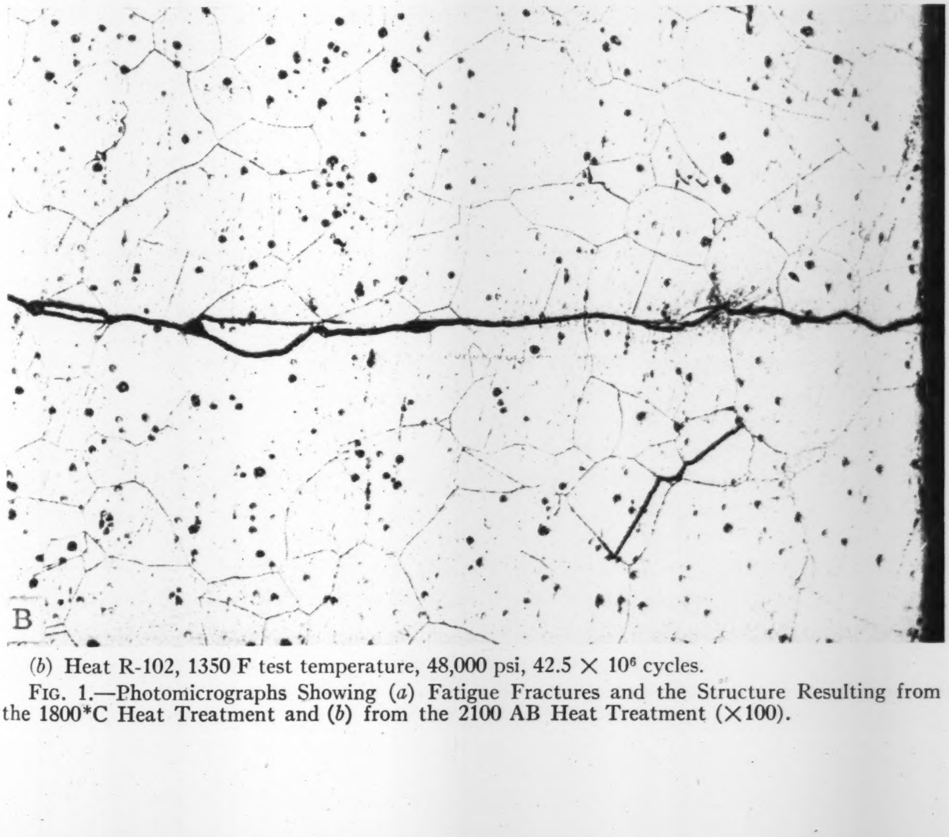
[c] Were not aged at 1200 F. This heat treatment has been assigned the code 2100AB.

The material for test specimens was hot forged to $\frac{3}{4}$-in. square, heated 1 hr at 1950 F and rolled to $\frac{19}{32}$-in. diameter, a reduction of area of 49 per cent. No recrystallization occurred during rolling, but on solution treating thereafter at 1800 F or higher temperatures, recrystallization to a fairly uniform grain size was completed within 20 min.

The heat treatments which have been used are summarized in Table II together with the code numbers which have been assigned to them to simplify discussion. The photomicrographs in Fig. 1 show



(*a*) Heat R-100, 1200 F test temperature, 88,000 psi, 10.2 × 10^6 cycles.



(*b*) Heat R-102, 1350 F test temperature, 48,000 psi, 42.5 × 10^6 cycles.

FIG. 1.—Photomicrographs Showing (*a*) Fatigue Fractures and the Structure Resulting from the 1800*C Heat Treatment and (*b*) from the 2100 AB Heat Treatment (×100).

longitudinal sections through the axes of two fractured fatigue specimens at 100× and illustrate the grain structures that result from the two most extreme solution treatments used. The specimen shown in Fig. 1(*a*) received a 20-min solution treatment at 1800 F followed by a 44-hr age at 1350 F, code 1800*C. The dark lines and bands in the grains near the surface, as seen at the right side of the photomicrograph in Fig. 1(*a*), are presumed to result from preferential etching of precipitate in slip planes that have been active in the cyclic straining. Presumably only the grains favorably oriented for slip exhibit these markings. The structure that results from a 60-min solution treatment at 2100 F followed by 20-hr aging successively at 1500, 1350, and 1200 F is shown in Fig. 1(*b*).

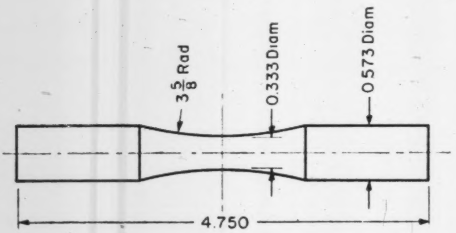


FIG. 2.—Fatigue Specimen.

Fatigue Test Program:

Fatigue tests were run at room temperature, 1200, 1350, and 1500 F. Table II lists the various heat treatments, test temperatures, grain sizes, hardnesses, and fatigue strengths at 10^8 cycles. The greatest amount of fatigue testing was done at 1200 F where the effects of six different heat treatments and of four different hardener contents have been studied. The emphasis on 1200 F fatigue tests of an alloy designed for resisting creep in the operating range of 1350 to 1500 F is based on the tendency for fatigue failures of rotating blades to be confined to the cooler portion of the blade near the disk.

The variations in heat treatment consisted of three different solution temperatures, 1800, 1950, and 2100 F; two solution times, 20 min and 60 min; and two variations in aging treatment, a single age of 44 hr at 1350 F and a triple age of 20 hr successively at 1500, 1350, and 1200 F. Since for applications involving creep, the multiple temperature aging is reported to provide a better combination of strength and ductility, a comparison of the effects of the two aging treatments on fatigue properties was also desired.

Although the effects of most of these variations were determined by a fatigue curve for only one heat, for the 1800*C[2] and the 2100 ABD[3] heat treatments, fatigue curves were determined for three heats having different titanium contents. At 1350 F, fatigue curves were determined for three heats of different hardener content with the 1800*C heat treatment and for two with the 2100 AB heat treatment. The effect of these same two heat treatments was studied at 1500 F with one composition. In addition to the high-temperature fatigue tests, a room temperature *S-N* curve was determined for one heat in order that an idea of the over-all fatigue strength *versus* test temperature relationship could be obtained.

Test Procedure and Results:

The fatigue specimen is shown in Fig. 2. These specimens were machined in a lathe and then polished down through 00 polishing paper. The final polishing was in the longitudinal direction.

The fatigue testing was done in Westinghouse High-Temperature Fatigue Machines, Type MD (**1**).[4] These are repeated-bending machines, the specimen being a non-rotating cantilever which, for these tests, was subjected to completely reversed bending at a frequency of 7200 cpm. Elastic behavior was assumed and the room-temperature dimensions were used in calculating the nominal stress. The specimens were held at the test temperature for from 15 to 20 hr before the fatigue tests were started. Failure was defined as a crack that had progressed inward for a distance of 0.05 to 0.1 in., which is the amount required to activate the automatic shut-down circuit of the fatigue machine.

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[2] This code number indicates a heat treatment consisting of a 20-min solution treatment at 1800 F followed by a 44 hr age at 1350 F. The heat treatments and their code numbers are given in Table II.

[3] Sixty-minute solution at 2100 F followed by the triple age.

[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 803.

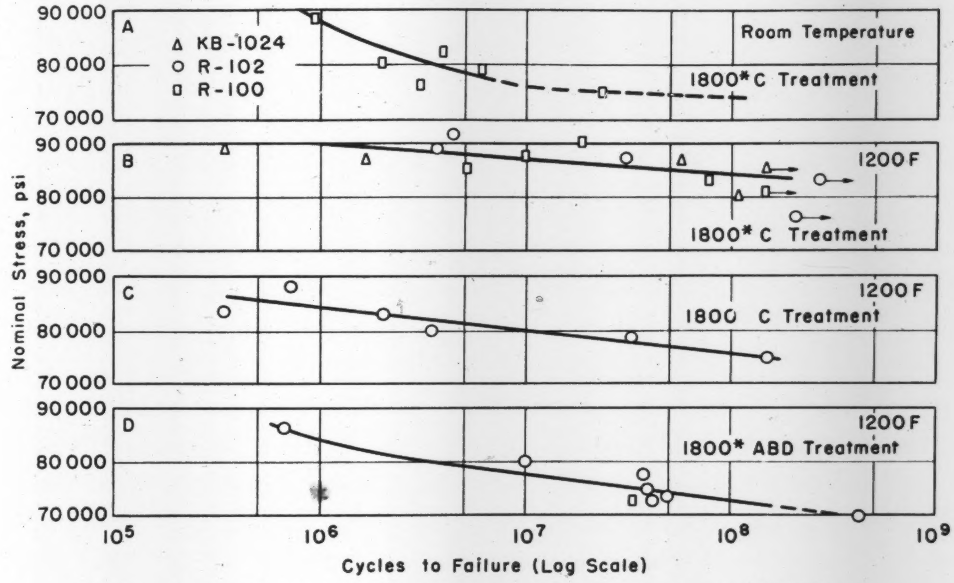

FIG. 3.—*S-N* Curves for Refractaloy 26 at Room Temperature and 1200 F.

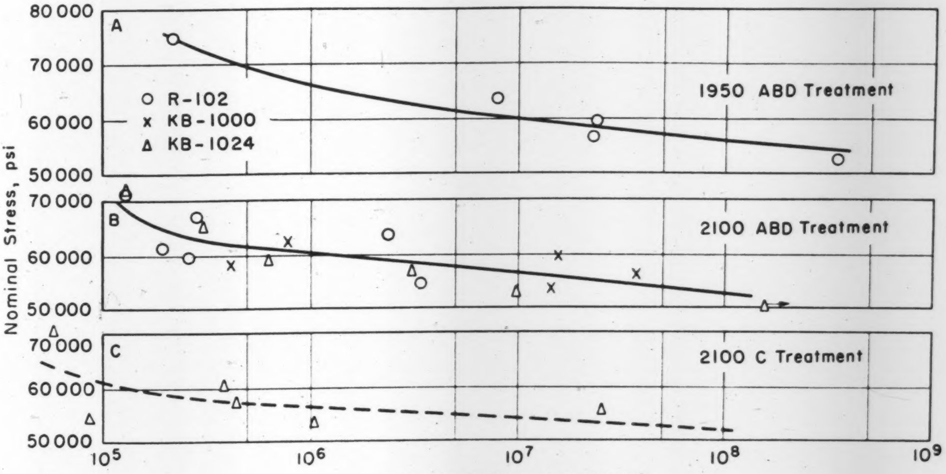

FIG. 4.—*S-N* Curves for Refractaloy 26 at 1200 F.

The fatigue test results are presented in the form of S-N curves in Figs. 3 to 6. In general, for the region beyond 5×10^6 cycles to failure, the data permit the high-temperature S-N curves to be represented by a straight line on the semilog plot. This is in agreement with the results of Toolin and Mochel (1). The fatigue strengths at one hundred million cycles as taken from these S-N curves are given in Table II.

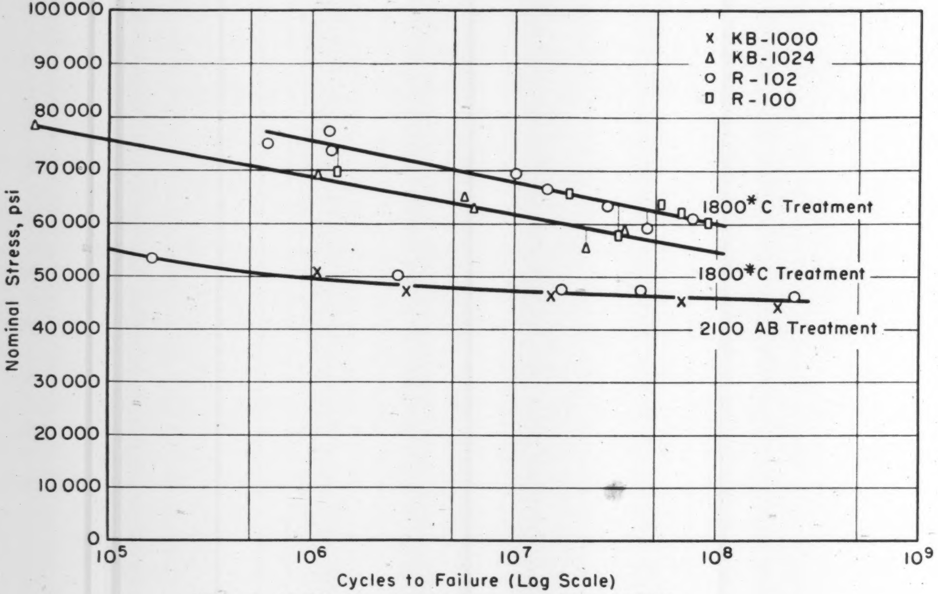

FIG. 5.—S-N Curves for Refractaloy 26 at 1350 F.

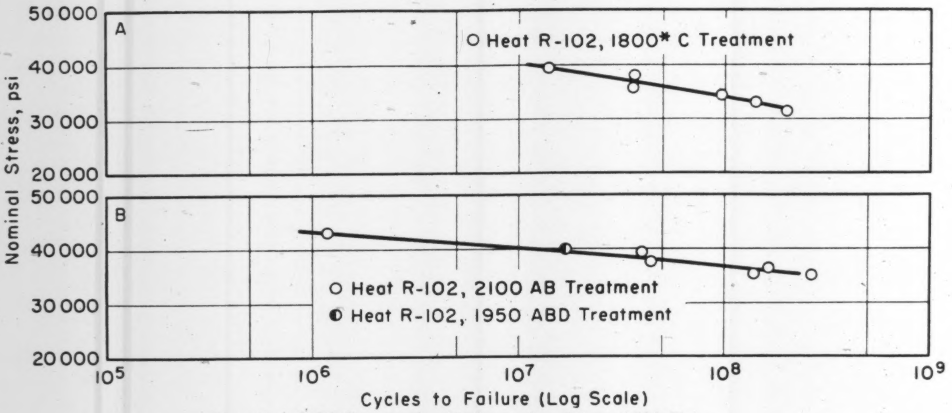

FIG. 6.—S-N Curves for Refractaloy 26 at 1500 F.

DISCUSSION OF RESULTS

Effect of Test Temperature:

The fatigue strengths at 10^8 cycles for all the various titanium contents, heat treatments, and test temperatures investigated are summarized in Fig. 7. This diagram is simplified by the fact that in the range of 2.5 to 3.2 per cent titanium, the elevated-temperature fatigue strength is apparently independent of the hardener content. A squared temperature scale was used so that the room-temperature fatigue strength could be shown without excessive crowding of the data at higher temperatures.

At room temperature the R-100 specimens with the 1800*C heat treatment have an average fatigue strength at 10^8 cycles of about 74,000 psi. This is less than the average fatigue strength of 84,000 psi which was obtained at 1200 F for similarly heat-treated specimens of R-100, KB-1024, and R-102. Presumably the greater fatigue strength at 1200 F is due to an aging phenomenon, influenced by strain, which occurs during the fatigue test.[5] The metal in the unstrained region also aged somewhat, for it hardens slightly in 250 hr as shown in Table II. Additional tests at temperatures lower than 1200 F would be required to establish the temperature at which the material has its maximum fatigue strength. Above 1200 F the fatigue strengths decrease more or less rapidly, depending upon the heat treatment; the specimens solution-treated at 1800 F and having a fine grain size show a much greater percentage drop between 1200 and 1500 F than those solution-treated at 2100 F and having a coarse grain size. At 1450 to 1500 F, both coarse- and fine-grained specimens have about the same fatigue strength.

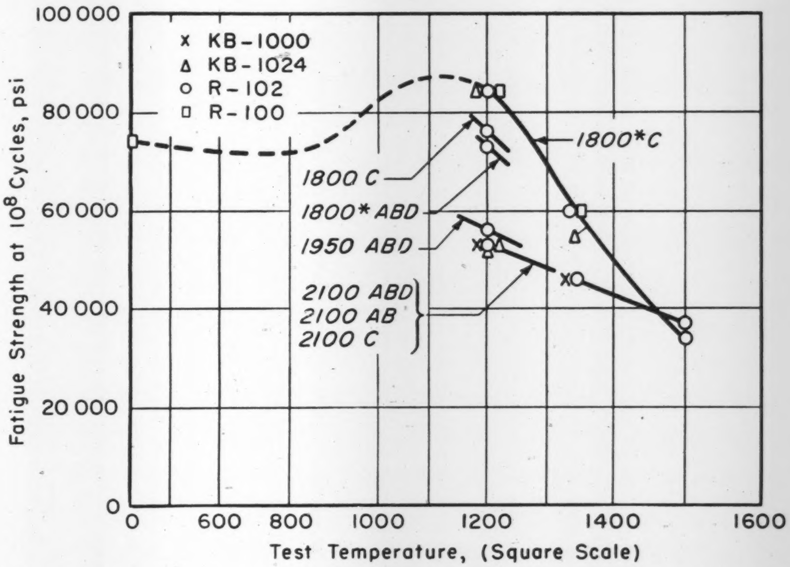

FIG. 7.—Effect of Test Temperature upon the Fatigue Strength of Refractaloy 26.

Effect of Titanium Content on Fatigue Strength:

The titanium content of Refractaloy 26 may be varied within fairly broad limits, depending upon the mechanical properties desired. Aged hardness increases approximately linearly with titanium in the range of 2.4 to 4.0 per cent, and both of these correlate well with elevated temperature tensile and creep properties. The variations in titanium analysis shown in Table I, however, have not resulted in appreciable differences in the 10^8 cycle fatigue strength at 1200 F. As shown in *B* of Fig. 3, the fatigue data at 1200 F for the KB-1024, R-102, and R-100 specimens which received the 1800*C heat treatment do not justify drawing other than one *S-N* curve for all three lots of specimens. *B* of Fig. 4 shows that the same situation exists for the KB-1000, KB-1024, and R-102 specimens with the 2100 ABD heat treatments, which were also tested at 1200 F. This seems to be ample evidence that variation in hardener content over the range investigated has no large effect on the 1200 F fatigue strength. This should not be taken as an indication that titanium in Refractaloy 26 has no effect on properties, for titanium-free alloys with the same matrix are known to be much weaker, but rather that in the range of 2.5 to 3.2 per cent titanium there is a leveling off in fatigue strength. An actual maximum in 100 hr rupture strength at 1200 F, as a function of titanium content in Discaloy, has been found (2).

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[5] The influence of aging during the test is also apparent in plots of yield strength *versus* test temperature.

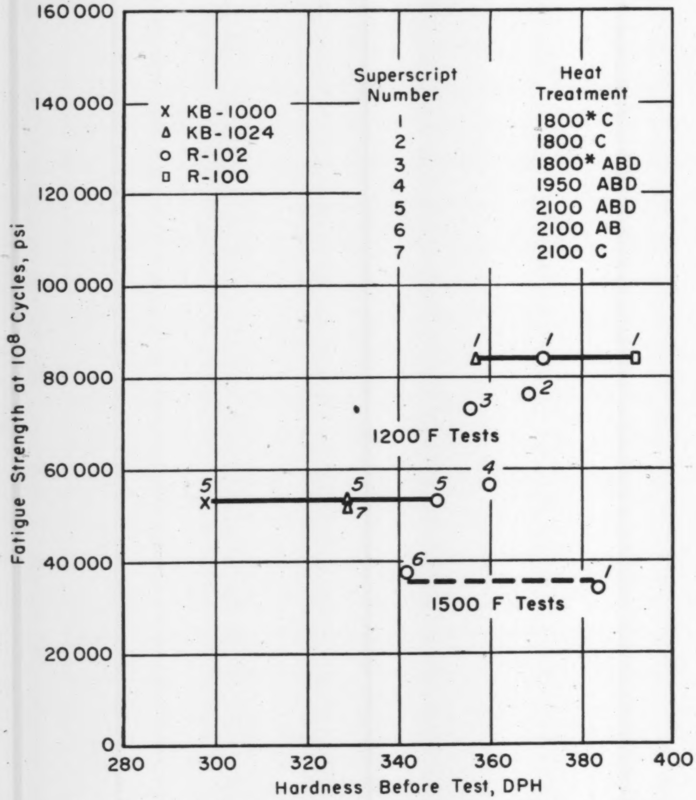

FIG. 8.—Hardness *versus* Fatigue Strength of Refractaloy 26.

At 1350 F, specimens from heats KB-1024, R-102, and R-100 were tested with the 1800*C heat treatment and as shown in Fig. 5 the points for the KB-1024 specimens are consistently, though perhaps not significantly, lower than those for heats R-100 and R-102. Although there is considerable scatter in the 1800*C data for the R-100 specimens, it appears that one *S-N* curve fairly well represents the data for both this heat and R-102. Heats KB-1000 and R-102 with the 2100 AB heat treatment were also tested at 1350 F. Five specimens of each material were tested and the data for these two heats of widely differing titanium content fall so closely together that there can be little doubt that one *S-N* curve should represent both heats.

Effect of Hardness on Fatigue Strength:

Table II gives the average hardness before test of the various lots of specimens. The fatigue strengths at 10^8 cycles are plotted against these hardnesses in Fig. 8. If one compares specimens of similar heat treatment in which the variations in hardness are due to differences in the titanium content, it is seen that at 1200 F fatigue strength does not change much with hardness. For example, in spite of the fact that the three heats tested with the 1800*C treatment have average hardnesses of 357, 372, and 392 DPH, they all have a fatigue strength at 1200 F of 84,000 psi. A similar result is found for the three heats tested with the 2100 ABD treatment, only here the variation in hardness is even greater, 298, 329, and 349 DPH. Apparently fatigue strength levels off or has a broad maximum in the hardness range of about 300 to 400 DPH.

Increasing the solution temperature of a given alloy slightly lowers the hardness and drastically lowers the 1200 F fatigue strength. However, to ascribe all of the drop in fatigue strength to this slight lowering in hardness seems inadvisable when grain size, for example, is simultaneously changed by significant amounts. Further indication of the lack of definite correlation between hardness and fatigue strength is given by the fact that the 1800*C treated KB-1000 specimens have a fatigue strength which is 50 per cent higher than that of the 1950 ABD treated R-102 specimens, even though the latter have a slightly higher hardness. To avoid undue complexity, the 1350 F results have not been plotted, but examination of Table II will reveal a lack of correlation similar to that at 1200 F. At 1500 F, as shown in Fig. 8, the 1800*C treated specimens are 40 DPH points harder than the 2100 AB treated ones, but the latter have a slightly greater fatigue strength.

In summarizing, it appears that over the range from 300 to 400 DPH, the hardness of Refractaloy 26 does not provide a good indication of the fatigue strength at 10^8 cycles for the temperature range from 1200 to 1500 F. This conclusion differs from the accepted one for carbon steel at room temperature where increased hardness is usually accompanied by increased fatigue strength, except that at high hardnesses fatigue strength reaches a maximum and then drops (3). For copper precipitation hardened with beryllium, the data of Anderson and Smith (4) indicate a lack of definite correlation between hardness and room temperature fatigue strength. Toolin and Mochel (1) give hardness values and fatigue strengths at elevated temperatures, 1200 to 1500 F, for a number of alloys, and while there appears to be an over-all tendency for higher hardness to be attended by higher fatigue strength, there are many exceptions to this trend.

Effect of Grain Size on Fatigue Strength:

In commenting upon the effects of grain size, it should be noted that when the grain size is changed by variation of heat-treatment procedure, there may be concomitant changes not necessarily clearly visible in the microstructure, such as the degree of solution and extent of homogenization of the hardeners and the distribution of precipitate on subsequent aging. The various grain sizes in the Refractaloy 26 specimens were obtained by varying the solution treatment over the range from 20 min at 1800 F to 60 min at 2100 F. In addition to the variation in solution treatment, there were also some differences in aging procedure for the various test lots. With these cautions one can refer to Fig. 9, which is a plot of the fatigue strength at 10^8 cycles *versus* the ASTM grain size number,[6] the latter varying over the range from ASTM No. 3 to 8.

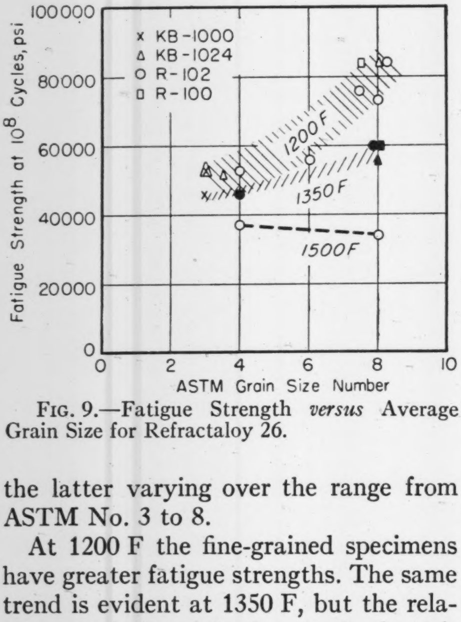

FIG. 9.—Fatigue Strength *versus* Average Grain Size for Refractaloy 26.

At 1200 F the fine-grained specimens have greater fatigue strengths. The same trend is evident at 1350 F, but the relative superiority of the finer-grained specimens is less than it was at 1200 F. The two series of tests at 1500 F indicate that there is relatively little difference in the fatigue strength at 10^8 cycles between specimens of grain size No. 4 and those of grain size No. 8. The fine-grained ones have a 10^8 cycle fatigue strength of 34,000 psi, while the coarse-grained ones have a slightly higher one of 37,000 psi. If the various heat treatments shown in Fig. 7 are associated with their resulting grain sizes, this figure can also be used to illustrate the relationship between grain size, fatigue strength, and test temperature.

The impression is widespread that a coarse grain size is essential for high creep or rupture strength. A gain in endurance strength by grain refinement would then incur a loss in creep strength. To check this, creep-rupture tests were made on Refractaloy 26 as solution treated at 1800 F to give a fine grain size. A heat of high hardener content, 3.2 per cent titanium, was used to compensate for the increase in ductility resulting from grain refinement, the fine-grained material thereby having creep ductility comparable with another heat containing only 2.8 per cent titanium given the 2100 F solution treatment. Compared on the basis of one per cent creep in 100 hr, the fine-grained material had higher strength at 1200 F, somewhat higher strength at 1350 F, and slightly lower strength at 1500 F (5). Thus gains in both creep and fatigue strength through grain refinement are possible in the range of 1200 to 1350 F.

Effect of Heat Treatment on Fatigue Strength:

The fatigue strength of this precipitation-hardened alloy is markedly affected by the variables of heat treatment, including solution temperature, solution time, and aging temperatures and times. The principal effects of the solution treatment appear to result from changes in grain size. The aging cycle selected and stabilization at the test temperature, or the lack of it, probably influence fatigue strength by varying the extent of precipitation on active slip planes during the fatigue text.

The maximum fatigue strength at 1200 F, 84,000 psi at 10^8 cycles, was obtained with the 1800*C heat treatment—20-min solution treatment at 1800 F followed by a 44-hr age at 1350 F. Maintaining the same aging treatment and increasing the solution time to 60 min caused the fatigue strength at 10^8 cycles to drop to 76,000 psi. A 60-min solution at 2100 F, followed by the same age as above, further reduced the fatigue strength to 52,000 psi. These large changes in the fatigue strength at 10^8 cycles were not accompanied by any large differences in the slopes of the *S-N* curves beyond 10^7 cycles.

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[6] Standard Classification of Austenite Grain Size in Steels (E 19 - 46), 1949 Book of ASTM Standards, Part 1, p. 1271.

The specimens solution-treated for 60 min at the intermediate temperature of 1950 F received a triple age (20 hr at 1500, 1350, and at 1200 F) rather than the single age of 44 hr at 1350 F. This treatment resulted in a fatigue strength of 56,000 psi. As there are no large differences in the slopes of the high-cycle end of the *S-N* curves at 1200 F for this alloy, it appears that the optimum solution treatment of Refractaloy 26 for maximum unnotched fatigue strength at 1200 F is 20 min at 1800 F. Lower solution temperatures or shorter times were not used because they would not have produced complete recrystallization.

At 1350 F the fatigue testing was confined to specimens which received either the 1800*C treatment or the 2100 AB treatment. The 1800*C heat treatment resulted in a fatigue strength at 10^8 cycles of 55,000 psi for KB-1024 and of 60,000 psi for R-102 and R-100. The latter fatigue strength is 30 per cent greater than the 46,000-psi value obtained for the KB-1000 and R-102 specimens which received the 2100 AB heat treatment. This is substantially less than the 59 per cent difference found for the corresponding heat treatments at 1200 F. While the effect of these heat treatments upon the 10^8 cycle fatigue strength is less at 1350 than at 1200 F, the effect upon the slope of the *S-N* curves is greater at 1350 F. Figure 5 shows that the slopes of the 1800*C-fatigue curves are considerably steeper than that of the 2100 AB-fatigue curve. From 10^7 to 10^8 cycles the 1800*C-fatigue curve decreases 8000 psi, while the 2100 AB curve drops only 1500 psi in the same range. Consequently, it appears that the superiority of the 1800*C-treated specimens will continually diminish as the number of cycles increases. If straight line extrapolations are made of the fatigue curve for the 1800*C-treated specimens of heats R-102 and R-100 and of the curve for the 2100 AB-treated specimens, they will intersect at approximately 1.5×10^{10} cycles. Of course, with the scatter in the test points and such a large extrapolation, only a limited amount of confidence can be placed in this. It should be noted that the 1800*C-treated material softens at 1350 F, as shown in Table II, while the hardness of the 2100 AB-treated material was not appreciably altered by 250 hr at this temperature. Thus perhaps the lower slope of the 2100 AB-fatigue curve is due to the greater stability at 1350 F of the 2100 AB-treated specimens.

At 1500 F the situation is reversed from that at 1200 and 1350 F, and the specimens of R-102 which were solution treated at 2100 F, code 2100 AB, have a fatigue strength at 10^8 cycles of 37,000 psi, which is slightly greater than the 34,000 psi obtained for the 1800*C-treated specimens. The difference in the slopes of the two *S-N* curves is also noteworthy.[7] Although both treatments result in fatigue strengths of about 40,000 psi at 10^7 cycles, from 10^7 to 10^8 cycles, the fatigue strength of the specimens that received the 1800*C treatment decreases 6500 psi, while that for the 2100 AB-treated specimens decreases only about half as much (slightly more than 3000 psi) over the same range. It thus appears that the superiority of the 2100 AB treatment may increase as the number of cycles increases.

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[7] It is because of the variation in slopes that it is inadvisable to predict the 10^8 cycle fatigue strength of the 1950 ABD-treated material from the one test which fell on the 2100 AB curve at 1.7×10^7 cycles.

In some cases, the fatigue strength at 1200 F can be appreciably altered by varying the aging treatment. Specimens solution treated for 20 min at 1800 F have been tested as aged for 44 hr at 1350 F, and as aged successively for 20 hr at each of the following temperatures: 1500, 1350, and 1200 F. The triple age resulted in a fatigue strength at 10^8 cycles of 73,000 psi, while the single age at 1350 F gave a fatigue strength of 84,000 psi, which is 15 per cent higher. From Fig. 4 it appears that the specimens which were solution treated at 2100 F for 60 min were much less affected by the aging treatment. Although there is a scarcity of tests at the high-cycle end of the *S-N* curve, *C* of Fig. 4, for the specimens with the single age of 44 hr at 1350 F, the data suggest that the 10^8 cycle fatigue strength for the single-aged specimens is not much different from that for the specimens with the triple age.

TABLE III.—TENSILE STRENGTHS AND FATIGUE RATIOS.

Heat	Heat Treatment Code No.	Diamond Pyramid Hardness Before Test	Tensile Strength, psi				Fatigue Ratio at 10^8 Cycles			
			Room Temperature	1200 F	1350 F	1500 F	Room Temperature	1200 F	1350 F	1500 F
No. R-102........	1800*C	377	187 000	151 000	134 000	87 000		0.56	0.45	0.39
No. R-100........	1800*C	388	191 000	158 000	121 000	88 000	0.39	0.53	0.50	
No. R-100........	1800*ABD	364	191 000	152 000				0.48		
No. R-100........	1800AB	359			111 000	78 000				
No. KB-1000.....	2100AB	290	144 000	125 000	99 000	62 000		0.42[a]	0.46	0.60[b]
No. KB-1024.....	2100AB	309	154 000	136 000	109 000	71 000		0.39[a]		
No. KB-1024.....	2100C	349	167 000	134 000	116 000	83 000		0.39		

[a] This fatigue ratio is based upon the 2100ABD fatigue strength and the 2100AB tensile strength.

[b] The fatigue strength of R-102 has been used to determine this fatigue ratio. As there is no appreciable difference in the 1200 F or 1350 F fatigue strengths of KB-1000 and R-102, it is assumed that they will also be approximately the same at 1500 F.

Fatigue Ratio:

In Table III some tensile strengths and fatigue ratios at 10^8 cycles are listed. The tensile strengths were determined on 0.357-in. diameter, 2-in. gage length specimens which were tested at a constant strain rate of about 8 in. per in. per hr. The fatigue tests were made at 7200 cycles per min. In regard to the fatigue ratios, it should be noted that several of the *S-N* curves have appreciable slopes at 10^8 cycles and thus the fatigue ratio would continually decrease if it were carried to greater numbers of cycles. It should also be noted that many high-temperature fatigue ratios differ from most room-temperature ones in that the high-temperature fatigue test may have been made at a temperature where the metal is not completely stable. With these general observations, attention can now be called to the fact that all the fatigue ratios lie between 0.4 and 0.6 and that, while the ratio for the fine-grained, 1800*C-treated specimens decreases in going from 1200 to 1500 F, the ratio for the coarser-grained 2100 AB-treated specimens increases. Furthermore, this discrepancy would increase if the fatigue ratio were to be based on a greater number of cycles, as the 1350 and 1500 F fatigue curves for the 1800*C-treated specimens have greater slopes at 10^8 cycles than do those for the 2100 AB-treated specimens. The fatigue ratios for R-100, 1800*C treatment, at 1200 and 1350 F are both greater than that at room temperature.

CONCLUSIONS

The conclusions to follow are based upon fatigue tests of the wrought austenitic precipitation-hardened alloy

Refractaloy 26. The machined and polished 0.333-in. minimum diameter fatigue specimens were tested with completely reversed bending at a frequency of 7200 cpm. The conclusions are probably generally applicable to austenitic alloys similar to Refractaloy 26.

1. The 10^8 cycle fatigue strength of 84,000 psi obtained at 1200 F is greater than those at any of the other test temperatures: room temperature, 1350, and 1500 F.

2. The fatigue strength is drastically affected by the solution treatment principally through the latter's effect on grain size. For a 1200-F test temperature, a 20-min solution treatment at 1800 F is superior to longer solution times or higher solution temperatures.

3. The superiority of the low solution temperature decreases as the test temperature is increased, and it appears that somewhere between 1450 and 1500 F the fatigue strength of material treated at 1800 F will be the same as that treated at 2100 F. At 1500 F and higher, the 2100-F solution treatment appears to be superior.

4. At 1200 F, finer-grained materials produced by low solution temperatures have higher fatigue strengths. The desirability of fine grains decreases as the operating temperature is increased, and, somewhere between 1450 and 1500 F, materials of ASTM grain size No. 3 to 4 should have about the same fatigue strength as those with No. 8. At still higher temperatures, coarser-grained material appears to be desirable.

5. For a given heat treatment, the fatigue strength does not change appreciably when hardness is varied up to 50 points, in the range of 300 to 400 DPH, by variation in titanium content within the limits of 2.5 to 3.2 per cent. That is, the fatigue strength *versus* hardness curve either levels off or has a broad maximum in the normal range of titanium contents for Refractaloy 26.

6. The hardnesses of this alloy, as varied by heat treatment or by both heat treatment and titanium content, do not correlate with the high-temperature fatigue strength.

7. Aging procedure affects the fatigue strength at 1200 F. Material solution treated at the lower temperatures appears to be more readily affected by variations of aging treatment.

8. In the 10^7 to 10^8 cycle region, the slopes of the S-N curves at 1200 F do not vary markedly for different heat treatments. However, at both 1350 and 1500 F these slopes are definitely steeper for materials solution-treated at 1800 than for those treated at 2100 F.

Acknowledgment:

The assistance of H. Scott, R. E. Peterson, and P. G. McVetty on this program is greatly appreciated. The testing work of Mrs. E. M. Schlotzhauer and E. K. Hann and the metallographic work of R. L. Anderson and his assistants are acknowledged.

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PLASTIC-FLOW AND WORK-HARDENING PHENOMENA IN MAGNESIUM ALLOYS DURING FIXED-DEFLECTION FATIGUE TESTS*

By Evan H. Schuette[1]

Synopsis

Whenever fatigue tests are conducted in fixed-deflection machines at stresses above that for which the load-displacement relationship is essentially elastic, the possibility exists that the load on the specimen will change during the course of the test. It is possible to introduce substantial errors in this manner. The phenomena involved have been investigated for several magnesium alloys, for both axial-load and repeated-flexure testing, and recommendations are made for testing procedures designed to minimize the undesirable effects.

The selection of equipment for conducting fatigue tests almost always involves a compromise among several conflicting factors. The following desiderata are usually considered:

1. Minimum initial cost.
2. Minimum space occupancy per machine.
3. Maximum speed consistent with material limitations (particularly temperature rise).
4. Best approximation to planned stress conditions.
5. Best correlation with service experience.
6. Maximum flexibility of operation.

The R. R. Moore rotating-beam type of machine is ideally suited to the first four of these conditions, but it has not been found to give good correlation with service experience on magnesium alloys, nor does it possess any great flexibility, being limited to the application of completely reversed stress. More recently, machines have been developed that will permit testing under axial load or repeated flexure with any mean stress and with complete or almost complete control of the constancy of load. Such machines, however, are generally large and expensive, thus limiting the amount of data they are capable of developing under budget restrictions.

A rather widely accepted compromise is the use of eccentric-operated equipment, such as the Krouse axial-load and repeated-flexure fatigue machines. These machines are relatively low in cost, occupy very little space per machine, operate at acceptably high speeds, provide types of test widely felt to offer good possibility of correlation with service experience, and offer complete flexibility of mean stress. However, they operate by transmitting a fixed or semifixed deflection to the test specimen, so that if the specimen undergoes any change of stiffness during the course of a test, the applied loads must undergo a corresponding change. Such changes can introduce substantial errors in meeting the planned stress conditions, particularly at high stresses and on initially soft materials.

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* Pesented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

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It was the object of this investigation to devise testing procedures that will minimize the undesirable effects of load changes in magnesium alloys during testing in Krouse fatigue machines. As a means to this end, a series of tests was conducted on sand-cast Dowmetal H-T4,[2] both in axial load and in repeated flexure, in which a large number of load cycles were applied and records of the stress-strain or load-deflection relationship were made at intervals throughout a test. Limited repeated-flexure tests were also conducted on the following Dowmetal alloys: sand-cast C-T6, FS1-H24 sheet, and FS1-0 sheet.[2]

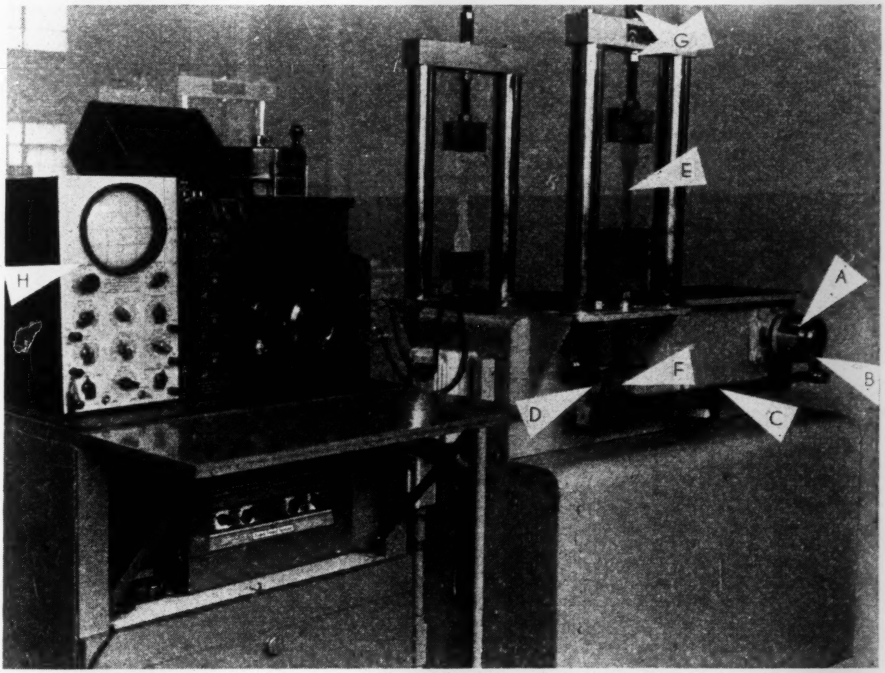

FIG. 1.—Krouse Axial-Load Fatigue Machine Equipped with Null-Indicating Oscilloscope.

FATIGUE MACHINES

The Krouse axial-load and repeated-flexure machines both derive load from the rotation of a flywheel to which is attached a crank arm with an eccentricity that normally remains constant during the course of a test. In the repeated-flexure machine, the other end of the crank arm is attached directly to the specimen, so that specimen deflection is fixed throughout a test. In the axial-load machine, however, a relatively long and flexible lever arm is interposed between the crank and the specimen. In the latter machine, then, if the specimen

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[2] Nominal compositions:

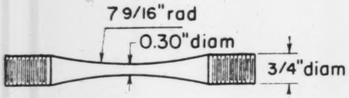
Alloy	ASTM Designation	Al, per cent	Zn, per cent
H	AZ63A	6	3
C	AZ92A	9	2
FS1	AZ31A	3	1

Tempers:

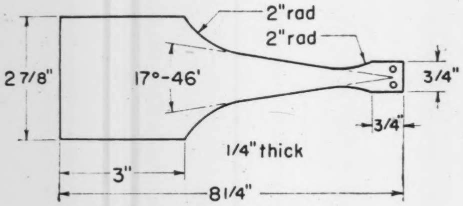
-T4	Solution heat-treated.
-T6	Solution heat-treated and precipitation-aged.
-H24	Hard-rolled and partially annealed.
-O	Fully annealed.

resistance increases, the amount of bending of the load-transmitting arm also increases, so that a somewhat reduced deflection is applied to the specimen. In this manner, part of the load increase that would result from an increasing stiffness of the test specimen is cancelled by a decreasing deflection. An approximate calculation, given in the Appendix, indicates that this compensating effect may be substantial.

The axial-load machine has an advantage over the repeated-flexure machine, in that the applied loads may be determined while a test is in progress. Electric resistance-wire strain gages are affixed to the elastic fulcrum hinges *D* and *F* (see Fig. 1). These are connected in a bridge circuit that is read by means of the null-indicating oscilloscope *H*, calibrated in terms of load.



Axial-Load Specimen



Repeated-Flexure Specimen

FIG. 2.—Test Specimens.

TEST PROCEDURES

Specimens used in the investigation were the same as those normally used in the Dow Chemical Co. laboratories for routine fatigue testing. These are illustrated in Fig. 2. In both types of machine, the test procedure consisted of running the machines in essentially the same way as in a normal fatigue test, but the test was stopped at intervals for the determination of load-strain or load-deflection curves. Details of this operation follow.

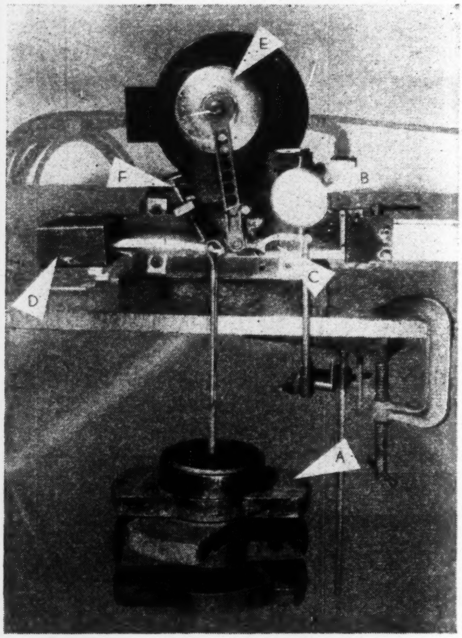


FIG. 3.—Test Setup in Krouse Repeated-Flexure Fatigue Machine.

Axial Load:

Specimen strain was observed by means of two A-7 resistance-wire gages attached on opposite sides of the specimen. Static strain only was recorded, using a standard Wheatstone bridge and galvanometer. Stress was obtained by means of readings taken from the fulcrum-hinge gages, in the manner previously described.

The first 250 cycles of load were applied to the specimens by means of hand operation of the eccentric, and points for a complete stress-strain loop were read at increasing intervals up to 250 cycles.

The eccentric was then adjusted to give dynamically the same deflection range as used on the 250th cycle, and 5000 cycles of load were run on by machine operation. Hand operation was then resumed for one cycle, and a stress-strain loop was obtained. After an additional 20,000 cycles, another loop was obtained. In a few cases, the test was stopped before completion of the full program.

In each test, on the first application of load, the machine was left locked in position for about 1 hr to allow for creep of the specimen. The specimen was then brought back to full load, and the unloading part of the cycle begun.

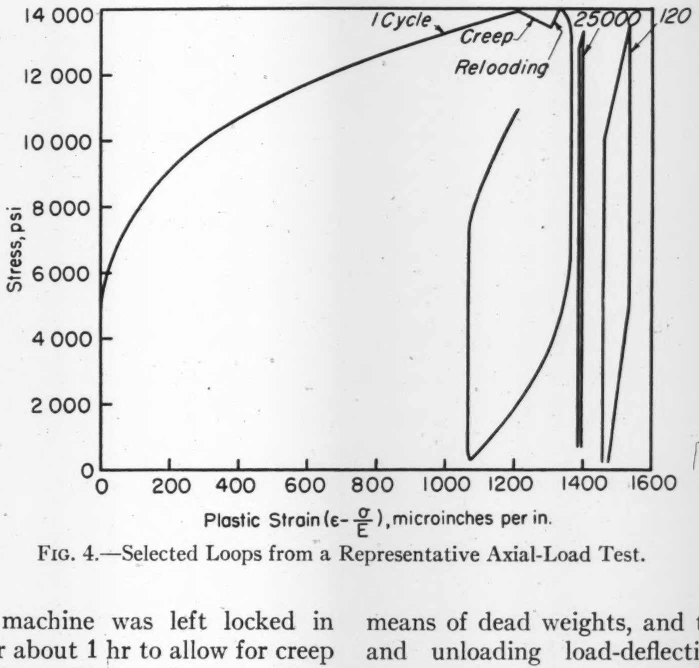


FIG. 4.—Selected Loops from a Representative Axial-Load Test.

Repeated Flexure:

Figure 3 shows the complete test setup used on the repeated-flexure machine. Desired maximum down-load was applied by dead weights *A* in increments. Corresponding specimen deflections were observed on the dial gage *B*, actuated through the lever arm *C*. An unloading curve was similarly determined. Adjustments were made in the vise *D* and the eccentric *E* so that a desired deflection range could be applied to the specimen by machine operation. In those cases where the minimum load was greater than zero, it was necessary to hold the specimen in a deflected position while changing from dead-weight to eccentric loading; this was accomplished by means of an adjustable hold-down screw *F*.

The specimen was first loaded by means of dead weights, and the loading and unloading load-deflection curves were taken. The eccentric was then adjusted to produce the desired deflection range, attached, and rotated by hand through the up-load portion of the cycle. The eccentric was detached, and a load-deflection curve for the down-load portion of the cycle was again taken, using dead weights. The eccentric was again attached, and $9\frac{1}{2}$ cycles were run on by hand operation, when another load-deflection curve was taken. Intermittent load-deflection curves were taken in this manner throughout the test. Up to 100 cycles, eccentric operation was done by hand. Subsequent cycling was accomplished by operation of the eccentric motor.

TEST RESULTS

Axial Load:

Figure 4 shows selected stress-strain loops from a representative test series on one specimen; elastic strain has been subtracted to permit an expanded abscissa scale. (In Fig. 4, ϵ is strain, σ is stress in psi and E is modulus of elasticity in psi. It is clear from these loops that the material has been considerably work-hardened by continued cycling. The amount of plastic flow occurring during a cycle has been greatly reduced after 120 cycles and reduced almost to zero after 25,000.

Possible effects of creep after that accounted for on the first cycle are somewhat obscure. For example, it is not immediately apparent why the loop after 25,000 cycles should show less residual plastic strain (displacement from initial modulus line or, in this case, from the left-hand edge of the graph) than that obtained after 120 cycles. A possible explanation lies in the testing technique. The first 250 cycles were applied by manual rotation of the eccentric, and it was not always possible to avoid loads slightly in excess of the intended maximum. The slope at the top of the initial loading curve indicates that a very slight increase of load would cause a relatively large increase of plastic strain, and it is this slope that would be followed any time the previous load limit were exceeded. Thus, a slight accidental overload at any time during the intermediate cycling could easily account for the displaced position of the loop for 120 cycles relative to the initial loop.

In a like manner, exact setting of the eccentric to produce the desired deflection range for dynamic loading (mechanical operation) was extremely difficult. In dynamic loading, a given eccentric setting will produce a greater deflection on the specimen than will the same setting when the eccentric is rotated slowly by hand. Moreover, the amount of this "dynamic overthrow" is dependent upon the resistance of the specimen to deflection, which is different for different load ranges and stages of work-hardening. Consequently, a single calibration curve could not be obtained, and the settings were of necessity only good approximations. If the total deflection range were accidentally shifted slightly downward, some compressive plastic flow would result, and the loop would be shifted leftward, as is the case for the loop at 25,000 cycles in Fig. 4.

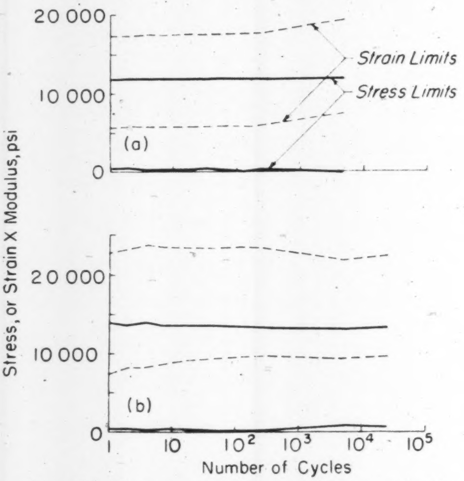


FIG. 5.—Representative Results of Axial-Load Tests on Sand-Cast Dowmetal H-T4.

Discussion of Axial-Load Results:

The plots of Fig. 5 are representative of all the axial-load results. They indicate that the strain range (and, therefore, also the deflection range) corresponding to the desired stress range had reached a state of reasonable constancy after 10^4 cycles. Related to an actual fatigue test, this means that if, at 10^4 cycles, the machine is producing in the specimen the stress limits that were desired, it will continue to do so thereafter, in so far as constancy is affected by work-hardening of the specimen. On the other hand, at the normal speed of 1800 cpm, the first 10^4 cycles are completed in less than 6 min, and in many cases appreciable creep will continue for substantially longer times. Even with the 1-hr waiting period used in the present tests, some further tendency to creep is indicated in Fig. 5 by the increasing strains needed to maintain the specified loads. Creep, however, has no effect on the obtained stress *range;* it tends to reduce the maximum and minimum stresses in equal amounts. Thus, while adjustments for work-hardening of the specimen necessitate changing the eccentric setting, adjustments for creep can be accomplished simply by taking up on the preload nuts (indicated by *G* in Fig. 1) while the machine is in operation.

From the above, a suitable setting-up procedure for the Krouse axial-load machine can be evolved. The procedure would require that immediately after the machine is started, the loads be read and the machine stopped for adjustments to both the preload nuts and the eccentric. Adjustments to the eccentric, however, would have to be continued only until the load *range* ceased to change. Subsequent adjustments would be for creep only and would not necessitate stopping the machine.

If this procedure is carefully followed, good results can be obtained on magnesium alloys even when failure occurs at as few as 10^4 cycles. If adjustments are frequent, very nearly constant load limits can be held after perhaps 2×10^3 cycles, which represents reasonable accuracy during 80 per cent of a test running to 10^4.

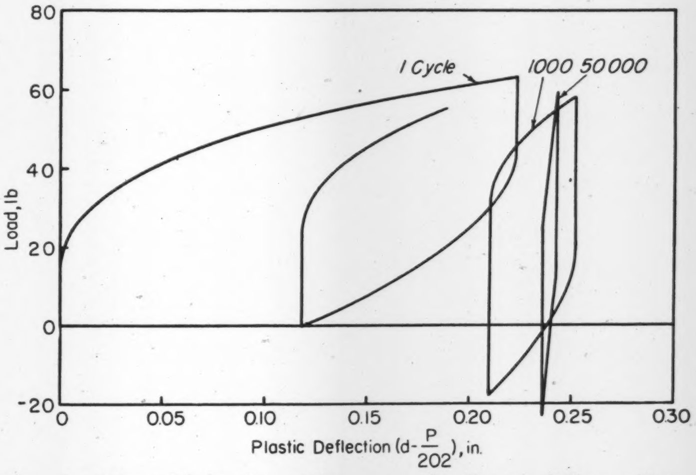


FIG. 6.—Selected Loops from a Representative Repeated-Flexure Test.

Repeated Flexure:

Figure 6 shows selected load-deflection curves from a representative repeated-flexure test series on one specimen. As with the axial-loading curves, elastic deflection has been subtracted to permit an expanded abscissa scale. (P = load, d = total deflection, P/d for elastic range = 202.) The same phenomena observed in axial loading are manifested here. The specimen action is, in this case, almost completely elastic after 50,000 cycles, but a substantial zero shift has occurred. Because the Krouse repeated-flexure machine does not incorporate provisions for reading the load being applied during a test, it is highly desirable that some means be found for predicting this zero shift so that it may be accounted for on the initial dead-weight loading.

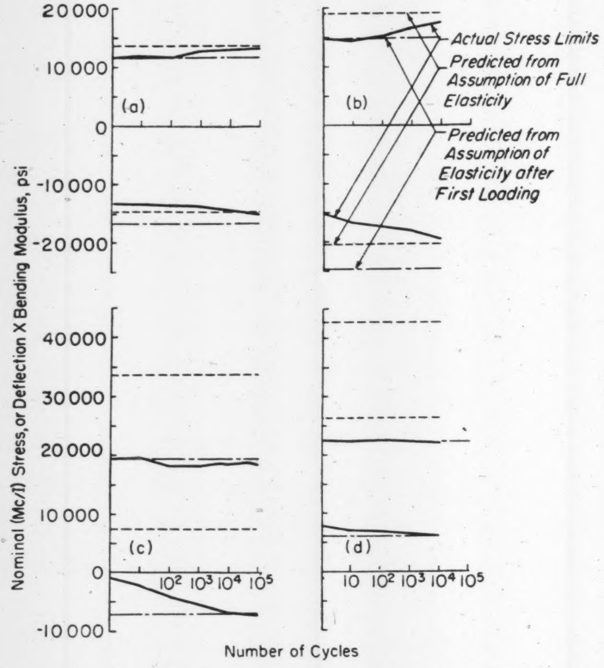


FIG. 7.—Representative Results of Repeated-Flexure Tests of Sand-Cast Dowmetal H-T4.

Representative results from the repeated-flexure tests are plotted in Figs. 7 to 10. These figures also show two sets of reference lines. The first set (dashed) represents the stress limits that are predicted by the deflection limits when it is assumed that all action is elastic from the beginning of loading. The positions of these lines are calculated by multiplying the deflection limits by the stress-deflection ratio indicated by the initial elastic portion of the load-deflection curve. The second set of reference lines (dot-dash) covers the same range as the first, but it incorporates a zero shift predicated on the assumption that specimen action is elastic subsequent to first reaching maximum load. In other words, zero stress is said to correspond to the strain intercept of the straight line obtained at the beginning of *un*loading.

Figures 7 to 10 are indications of the nature of all the results and show, for sand-cast H-T4 and C-T6, and for FS1-H24 and FS1-0 sheet, the changing specimen loads produced by maintaining constant applied deflections during the course of a fatigue test.

Discussion of Repeated-flexure Results:

Curves *A* and *B* of Fig. 7 show that, at a ratio of minimum stress to maximum stress, designated by R, of -1 (completely reversed stress), the actual loads approach very closely the predicted values based on fully elastic action within perhaps 10^4 cycles. As R is increased, the actual limiting values of load tend to fall below such a prediction, gradually approaching the predicted values based on elastic action starting with the first unloading. By the time R reaches zero (note curve C), this latter prediction agrees very well with the realized values. These facts indicate possible setting-up procedures for certain R-values, as follows:

1. $R = -1$: Load specimen with dead weights within its elastic range, and determine load deflection ratio. From this, calculate the desired deflection range, assuming specimen action will be fully elastic.

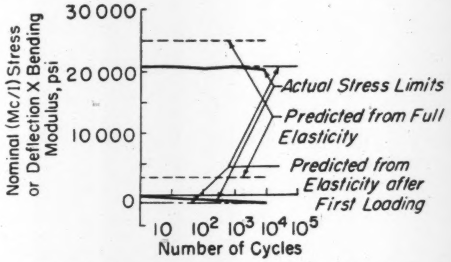


Fig. 8.—Representative Results of Repeated-Flexure Tests on Sand-Cast Dowmetal C-T6.

2. $R \geq 0$: Load specimen with dead weights to full maximum load intended, then unload, and determine slope of the initially straight unloading curve. Calculate desired deflections on the assumption that subsequent specimen action will continue to follow this straight line.

These procedures will assure dependable results for their particular R-values, providing failure does not occur before about 10^5 cycles. Figures 8 to 10 indicate suitability for the other three materials as well as for H-T4. When failures are likely before 10^5 cycles, in a material subject to considerable work-hardening, such as H-T4, it may be necessary to stop the test at frequent intervals, determine the actual deflection limits then corresponding to the desired load limits, and set the machine accordingly. Such a procedure, of course, tends to defeat the purpose of the small, simple machine and cannot be highly recommended.

Possible Effects of Loading Rate

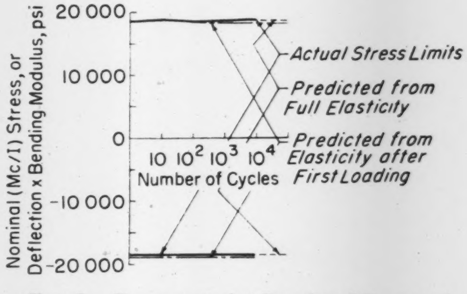


Fig. 9.—Representative Results of Repeated-Flexure Tests on Dowmetal FS1-H24 Sheet.

The technique used in these tests might reasonably be questioned on the basis that the loading rate was not constant for all cycles. On those cycles for which load-deflection curves were taken, the operation was at a rate of perhaps 0.1 cpm, intermediate manual cycles were of the order of 5 cpm, and mechanical operation was at as much as 1800 cpm. It is in order to consider the comparative effects of such loading rates. At 1800 cpm, the full load is attained in 0.033 sec. Clark and Wood[3] demonstrated substantial delays in the onset of plastic deformation in 0.05-sec loading of steels. but they found no such effect in aluminum alloys 24S-T3 or 75S-T6. They conclude that "a definite time delay in the initiation of plastic deformation is associated only with materials from which the static stress-strain curve exhibits a definite yield point." On the other hand, Clark[4] has shown that at rates of extension of 50 ft per sec or more, a definite yield point, substantially higher than the conventional yield strength (0.2 per cent offset), could be developed in magnesium alloys not otherwise exhibiting this phenomenon. For his specimens of 1-in. length, however, a velocity of 50 ft per sec corresponds to the attainment of maximum load, or a strain of 5000 microinches per in. or less, in something less than 0.00001 sec. From these results, it would appear that little difference in the stress-strain relationship is to be expected between the two extreme speeds of $\frac{1}{10}$ and 1800 cpm.

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[3] D. S. Clark and D. S. Wood, "The Time Delay for the Initiation of Plastic Deformation at Rapidly Applied Constant Stress," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, pp. 717–735 (1949).

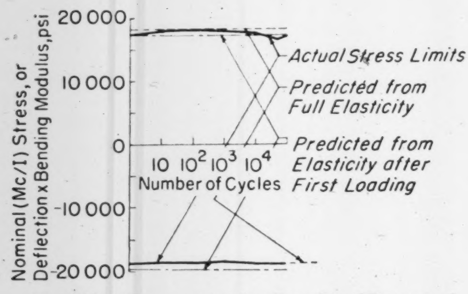

FIG. 10.—Representative Results of Repeated-Flexure Tests on Dowmetal FS1-0 Sheet.

It is not as certain that the internal reactions of the specimens were independent of speed. Wood and Head[5] have recently shown that the disorientation that occurs in pure copper and pure aluminum when cyclically loaded at a slow rate is very markedly reduced under rapid loading, and that the transition—a rather pronounced one—takes place somewhere between 300 and 400 cpm. Precisely what this may mean in regard to the present tests, the author is not prepared to state. In general, there is no strong evidence in Figs. 5, 8, 9, and 10 that a change in trends occurs as the specimen is changed from static to dynamic loading, whereas some of the curves of Fig. 7 indicate some increase in the rate at which complete elasticity is approached after the initial 100 manual cycles. Fortunately, as long as the only evidence of change indicates, if anything, an increasing hardening rate with dynamic cycling, it need not be a cause for concern. A change in this direction would serve to strengthen the conclusions and recommendations given.

CONCLUSIONS

1. A magnesium-alloy fatigue specimen tested at relatively high stress under conditions of fixed deflection, whether in axial load or in repeated flexure, may undergo substantial increases in applied load during the course of a test as a result of progressive work-hardening of the specimen.

2. Depending on type of test and stress levels, these increases are generally nearly complete at from 10^3 to 10^5 cycles of load.

3. When this effect is recognized, suitable techniques can be devised that will make possible obtaining good results in the Krouse axial-load fatigue machine for lives as short as 10^4 cycles.

4. Suitable techniques can be devised for running high-stress tests in the Krouse repeated-flexure fatigue machine at R (ratio of minimum stress to maximum stress) of -1 or ≥ 0, provided failure, particularly in the softer alloys, does not occur very much short of 10^5 cycles.

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[4] D. S. Clark, "The Influence of Impact Velocity on the Tensile Characteristics of Some Aircraft Metals and Alloys," NACA Technical *Note 868*, Nat. Adv. Committee for Aeronautics, October, 1942.

[5] W. A. Wood and A. K. Head, "Some New Observations on the Mechanism of Fatigue in Metals," *Journal*, Inst. Metals, Vol. 79, pp. 89–102, April, 1951.

APPENDIX

EFFECT OF MACHINE FLEXIBILITY ON LOAD-TRANSMISSION CHARACTERISTICS OF A KROUSE AXIAL-LOAD FATIGUE MACHINE

The Krouse axial-load fatigue machine was illustrated in Fig. 1. While the complete stress system from point of load application to reaction is an exceedingly complicated one, an approximate calculation is possible if the system is reduced to the two primary flexible elements involved, the load-transmitting arm and the test specimen, as illustrated in Fig. 11. Figure 11 also shows the coordinate and dimensioning systems used. For the machines in use in the Dow Metallurgical Laboratories, the cross-section of the load-transmitting arm is such that its moment of inertia is given approximately by the following:

$$\begin{aligned} I &= 0.005x^{4/3} \qquad 0 \leq x \leq a \\ I &= \infty \qquad a \leq x \leq b \ldots\ldots (1) \end{aligned}$$

We have the classical formula

$$E_a I \, \frac{d^2y}{dx^2} = -M \ldots\ldots\ldots\ldots (2)$$

where:

E_a = modulus of elasticity of arm, and

M = bending moment.

Inserting appropriate values for the moment of inertia and bending moment yields, for $0 \leq x \leq a$,

$$\frac{d^2y}{dx^2} = -\frac{200P_s(b-a)}{bE_a} x^{-1/3} \ldots\ldots (3)$$

and for $a \leq x \leq b$,

$$\frac{d^2y}{dx^2} = 0 \ldots\ldots\ldots\ldots (4)$$

Integration of Eqs 3 and 4 and insertion of the known boundary conditions yields, for $0 \leq x \leq a$,

$$y = \frac{60P_s(b-a)}{bE_a} \left[\left(5 - 2\frac{a}{b}\right)a^{2/3}x - 3x^{5/3}\right] \ldots\ldots\ldots\ldots (5)$$

from which

$$y_s = \frac{120P_s a^{5/3}}{E_a}\left(1 - \frac{a}{b}\right)^2 \ldots\ldots (6)$$

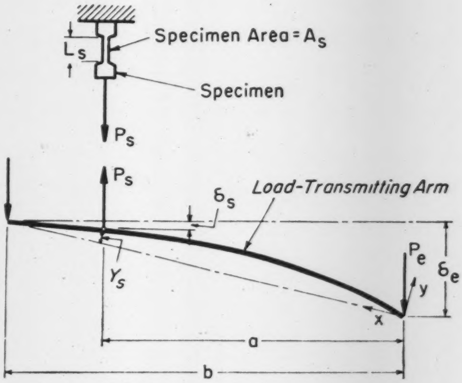

FIG. 11.—Schematic of Load-Transmitting System and Symbols used in Calculations.

From geometry (see Fig. 11), and neglecting small differences in directions,

$$\delta_s = \delta_e \frac{b-a}{b} - y_s \ldots\ldots\ldots\ldots (7)$$

Also, from consideration of the specimen reaction, δ_s is given by

$$\delta_s = \frac{P_s L_s}{A_s E_s} \ldots\ldots\ldots\ldots (8)$$

where E_s = effective modulus of elasticity of specimen.

Equating Eq 7 to Eq 8 and solving for P_s gives

$$P_s = \frac{\delta_e}{\frac{L_s}{A_s E_s}\left(\frac{b}{b - a}\right) + \frac{120a^{5/3}}{E_a}\left(\frac{b - a}{b}\right)} \quad \ldots (9)$$

For a representative test specimen in this machine, the following values may be taken:

$E_a = 29 \times 10^6$ psi
$a = 26$ in.
$b = 29$ in.
$L_s = 2$ in.
$A_s = 0.07$ sq in.

Substituting these values into Eq 9 yields an expression that shows the effect of the specimen modulus on the relationship between deflection applied at the eccentric (δ_e), and load on the specimen (P_s), as follows:

$$P_s = \frac{\delta_e}{\frac{276}{E_s} + 97.2 \times 10^{-6}} \quad \ldots\ldots (10)$$

As an example of the way in which Eq 10 translates into actual load figures, consider a specimen which, in the early stages of cycling, had an effective modulus of elasticity—that is, a secant modulus connecting the ends of the load cycle—of 3×10^6 psi. Subsequently, the specimen work-hardened sufficiently to increase this modulus to 6×10^6 psi. Then from Eq 10 the following values can be determined:

P_s (with $E = 3 \times 10^6$) $= 5290\ \delta_e$
P_s (with $E = 6 \times 10^6$) $= 6980\ \delta_e$

In this case, when the modulus of elasticity of the specimen doubled, the load increased by only 32 per cent. The rest of the change was absorbed by additional bending of the load-transmitting arm. Had a specimen length of 1 in., instead of 2 in., been used, the figure would have been further reduced to only 19 per cent. Only the reduced section of the specimen should be considered here, because the remainder is not at sufficiently high stress to undergo the same large changes of modulus.

It is seen that the Krouse axial-load fatigue machine, when used on specimens undergoing substantial work-hardening during test, is neither a constant-deflection nor a constant-load machine, but its characteristics lie somewhere between these limiting types.

DISCUSSION

Mr. W. N. Findley.[1]—In the testing technique employed by the author, adjustments of the constant amplitude-of-deflection fatigue machine were made at intervals to maintain a constant amplitude of force. It is not clear to me why constant-force conditions are (*a priori*) better than constant-deflection conditions.

As I see it, both leave much to be desired in that constant-load testing is not necessarily constant-stress testing and constant-deflection testing is not necessarily constant-strain testing, especially in the vicinity of a fatigue crack or a region of slip.

Figure 12 may be of interest in connection with the question of constant load *versus* constant-deflection testing in fatigue. In this figure are shown static load-deflection data for a specimen of 76 S – T 61 aluminum alloy. On the first loading considerable yielding occurred as evidenced by a curved load-deflection relation; but on unloading, this relation was substantially linear and parallel to the initial loading line. On reloading, the relation was also linear. When the maximum deflection was increased, the unloading and reloading curves were also substantially linear.

This observation indicates that the amplitude of loading was substantially the same whether yielding occurred on the first loading or not. The effect of the yielding was to reduce the maximum stress below that expected from elastic behavior.

On most fatigue machines, mean stresses (when provision is made for them) are produced by means of a deflected spring. The spring may be the specimen or it may be a separate spring. If the specimen yields, the mean load and the maximum load change. Thus, adjustments must be made manually or automatically, if it is desired to maintain a constant mean load or constant maximum load. This is true whether the machine is a constant amplitude-of-load or constant amplitude-of-deflection type.

Mr. B. J. Lazan.[2]—Certainly it is true that in service there exist both constant load and constant deflection conditions of loading, and for that reason both are important in the laboratory. However, practically all fatigue data are reported in terms of *S-N* diagrams rather than strain *versus* number of cycles diagram. Thus, if constant deflection conditions are employed in the laboratory, the results should be carefully considered before plotting them in an *S-N* diagram.

With regard to the question as to how different these two tests are, generalization is rather difficult. There are significant differences in some materials. In stable materials, that is, materials which do not change their modulus of elasticity during the course of cyclic tests, the two types of tests should produce the same results.

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[2] Director of Engineering Experiment Station and Professor of Materials Engineering, University of Minnesota, Minneapolis, Minn.

We have performed a number of tests on the damping, elasticity, and fatigue properties of various materials up to 130 per cent of the fatigue limit, and to date the only material with a stable modulus is cast iron. Even near or below the fatigue limit, most materials display a rather significant change in modulus of elasticity.

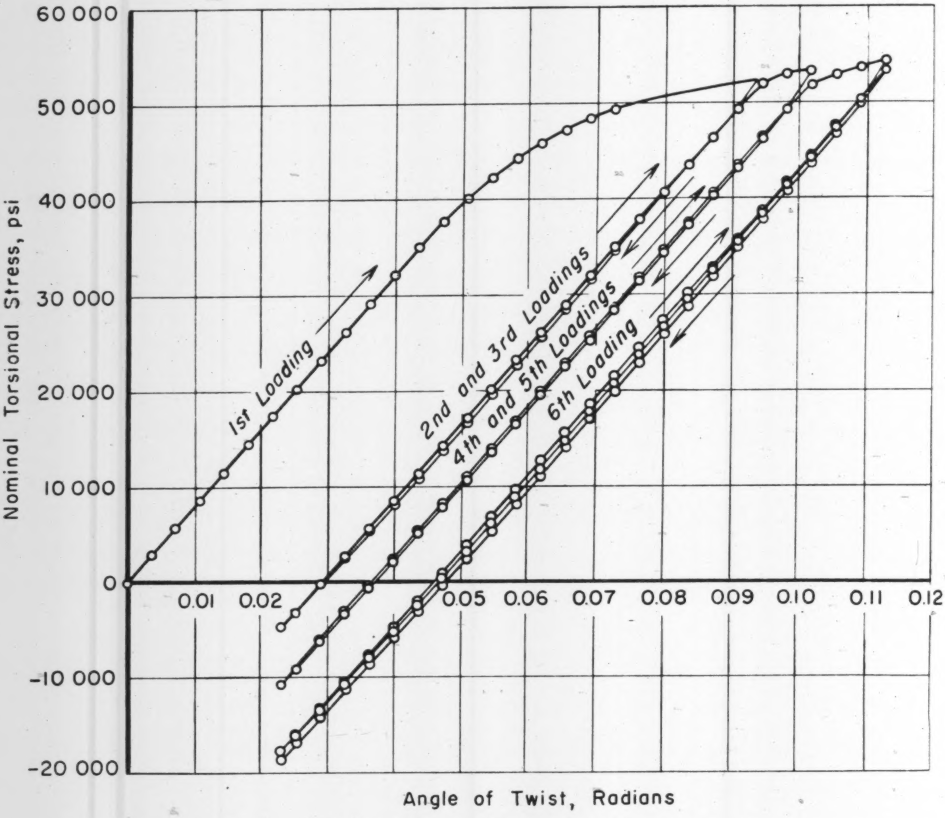

FIG. 12.—Load Deflection Test of Fatigue Specimen in Torsion.

I should like to ask the author whether in any of his work he noticed any change in stress which could be associated with a change in modulus. I believe most of his effects were associated with the change of permanent set during the course of the tests.

I do not agree with the author that the constant-stress machine as described is more expensive and harder to use than the constant-deflection machine.

MR. J. O. ALMEN.[3]—The effects of the plastic flow observed in the specimens described by the author take an added significance when we realize that local plastic flow necessarily means that the plastically deformed metal becomes residually stressed, in an opposite sense, to the stress causing the deformation. This is always true unless the plastic deformation is uniform through the stressed section or unless residual stress of opposite sign was present in the specimen prior to the observed plastic flow.

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The effect of the residual stress induced by local plastic flow will be advantageous or detrimental to the fatigue strength of the specimen, depending upon whether the applied stress is of the opposite or the same sign as the induced residual stress.

MR. E. H. SCHUETTE (*author's closure*). —Mr. Findley asks why we desire constant load in fatigue testing. It is simply because this is what designers have asked for. They are in the habit of talking in terms of stress and want their data furnished in those terms. I hold no brief for constant-load testing from an academic point of view, and indeed I have seen frequent situations where the strain was a far more significant parameter than the stress. In some recent work at the University of California,[4] fatigue tests were run with strain as a parameter. In reporting this work, the authors showed results quite similar to those of the present paper; with strain held constant, the stress level increased either throughout the test or through the early stages of a test.

In speaking of constant-load machines, I was referring particularly to the type of machine on which both mean- and maximum-load adjustments are made automatically and continuously, rather than manually and intermittently.

Mr. Lazan asks if any of the changes in stress are associated with a change of modulus. We detected no change in elastic modulus during any of the tests, but I believe that what is intended in the question is the secant modulus connecting the end points of the single-cycle load-deflection diagram. This latter modulus showed substantial increases, as evidenced by the closing up of the load-deflection loop. Any change in stress range for given strain limits is directly associated with this change of the secant modulus; any change in position of the entire cycle along the strain axis, on the other hand, is associated with creep.

Mr. Almen mentions the probable presence of residual stresses in the specimen. We are, of course, fully aware of their existence, particularly in testing of repeated-flexure specimens. We simply have not found time as yet to study this phase of the problem. Our efforts to date have been aimed at control of the applied loads. The reaction to these loads in terms of the stresses existing in the specimen is the logical next step.

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[4] J. W. Riches, O. D. Sherby, and J. E. Dorn, "The Fatigue Properties of Some Binary Alpha Solid Solutions of Aluminum," *Transactions*, Am. Soc. Metals, Vol. 44, p. 882 (1952).

FATIGUE OF 76S-T61 ALUMINUM ALLOY UNDER COMBINED BENDING AND TORSION*

By William N. Findley[1]

Synopsis

Fatigue data for 76S–T61 aluminum alloy are presented for several combinations of bending and torsion. The special fatigue equipment for these tests is described. Fatigue data in torsion are presented for two different type fatigue machines and results of static tests are tabulated.

The literature on the effect of combined stress in fatigue is reviewed and the results of the present series are compared with various theories. A new way of describing the state of stress and a new criterion for combined stress fatigue are discussed; and a new mode of presentation of combined stress results is described. A possible correction for anisotropy, and energy theories of fatigue under combined stress are discussed.

The problem of fatigue failure of materials under different states of combined stress is of immediate importance in the design of many components of all types of machinery and transportation equipment. It has perhaps even greater importance as a key problem, the solution of which would contribute greatly to a better understanding of the phenomenon of fatigue failure and how to control it.

STATUS OF THE PROBLEM

Combined Stress:

The effect of different states of stress on the fatigue strength of metals has been studied sporadically since 1916 (**1**).[2] The problem has been difficult and very time-consuming because of the large number of tests involved, the difficulty of designing suitable testing machines, the difficulty of devising and maintaining testing techniques which do not influence the results, and because of the inherent scatter in results of fatigue tests.

Most of the fatigue tests under combined stress which have been reported involved tests in axial load, bending, torsion, and various combinations of two of these three (**1–18**). The most extensive of these were reported between 1935 to 1949 by H. J. Gough (**8, 9, 10, 18**) for tests of steels and cast irons. A few fatigue tests of tubes under combined axial load and internal pressure have been reported for cast iron (**19**), carbon steel (**19–22**) and aluminum alloy (**23, 24**). Other tests of steels have been analyzed in which combined stresses were produced by axial or diametrial loads on disks (**25**), by circumferential notches on solid and hollow shafts (**25**), and by bending or torsion of engine crank shafts and connecting rods (**26**).

Some investigators have described machines for fatigue tests under combined stresses (**27–29**) without presenting new data. And others have presented analyses which they correlated with existing data (30–39).

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 831.

Various conclusions have been reached by the different investigators concerning the applicability of the well-known theories of failure to the results of fatigue tests under combined stress.

Gough (8) found for high strength cast iron that the results of tests under combined bending and torsion agreed with the theory of a limiting principal stress but that tests of other steels and cast irons were in approximate agreement with various theories. He finally concluded that none of the rational theories of failure either did or could explain fatigue failure since the relationship between the fatigue strength in bending and that in torsion was not the same for all materials as required by the rational theories. Hence Gough proposed two empirical elliptical equations, the ellipse quadrant for ductile metals and the ellipse arc for cast irons. These equations avoided the difficulty by including as arbitrary constants the values of the fatigue strengths in bending and in torsion.

Other investigators of combined bending and torsion fatigue have reported the following conclusions: Narmore (11) found the data from a hard SAE 4634 steel fit the ellipse quadrant equation and was nearest to the theory of a limiting total strain energy; Nisihara and Kawamoto (13) testing an annealed 0.34 per cent carbon steel concluded that the criterion of a limiting energy of distortion best represented their data and that the direction of the surface of fracture was perpendicular to the greatest principal stress; and Sauer (16) in tests of 14S-T aluminum alloy concluded that his data were closest to the theory of a limiting principal shearing stress.

Maier's (19) tests of tubes of steel, cast iron, and brass under fluctuating internal pressure were inconclusive but indicated that a theory of a limiting principal stress might apply. Morikawa and Griffis (21) concluded from tests of tubes of mild steel under fluctuating internal pressure and axial load that "the results do not seem to permit verifying or establishing a theory of fatigue failure under combined stress which is appreciably different from the maximum stress theory for this ductile metal." Majors, Mills, and MacGregor (22) concluded from tests of tubes of mild steel under pulsating internal pressure and axial load that the distortion energy theory was the best fit to their data. Marin and Shelson (23) reported so much anisotropy in the 24S-T aluminum alloy tubes they tested under internal pressure and axial load that comparisons with existing theories were not possible.

Sawert (25), testing disks and notched bars of mild steel and heat-treated chromium-vanadium steel, concluded that the test results most closely approximated those predicted by the theory of a limiting energy of distortion.

An examination of most of the reports on fatigue tests under combined bending and torsion (8, 9, 10, 11, 13, 16, 17, 18) indicate that the effect of possible anisotropy in the material was not considered. In a discussion of Gough's most recent paper (18) on this subject the author (40) suggested that anisotropy may be the reason that the ratio of fatigue strength in bending to that in torsion was not the same for all materials. A procedure was also suggested for correcting for anisotropy. When this correction was applied to the theory of a limiting principal shearing stress the resulting expression was found to be identical with the empirical equation proposed by Gough. This problem is discussed in greater detail in another paper (41) and a report submitted to the NACA (42).

Examination of the data presented by

Morikawa and Griffis (21) indicated for the combinations of stress employed that the principal stress and shearing stress theories are identical. Also the comparison made by Majors, Mills, and MacGregor (22) between the several theories and their data was based on the tacit assumption that the fatigue strength in bending was precisely determined and that all uncertainty or scatter lay in the results obtained under other states of stress. If one removes this restriction it is found that the theory of a limiting principal shearing stress fits the data better than the other theories considered by the authors as shown elsewhere (41–42).

Sawert (25) also has assumed that the fatigue strength under uniaxial stressing was exact and that all scatter must be in the data from the remaining states of stress. Again if this restriction is removed the data are found to fit the theory of a limiting principal shearing stress as well as, if not better than, the theory he selected.

Gadd, Zumda, and Achiltree (26) concluded from their tests of engine components that the results are best predicted by what they called an equivalent shear energy stress (porportional to the octahedral shearing stress). However, their analysis appears to be based on the maximum spread of the data.

If statistical measures of dispersion are applied to the seven test values reported by Gadd, Zumda, and Achiltree it is found that the standard deviation expressed as a percentage of the mean of the values is slightly in favor of the equivalent shear energy stress while the average deviation from the mean expressed as a percentage of the mean is slightly in the favor of the principal shear stress theory. Also if the value having the greatest deviation from the mean is eliminated both measures of dispersion in the remaining six values show about 1 per cent dispersion for the principal shear stress compared to 2 to 3 per cent for the equivalent shear energy stress.

The above analysis suggests that none of the available test data disagree with the theory of a limiting principal shearing stress.

SCOPE AND PURPOSE OF INVESTIGATION

The present investigation was undertaken to determine the effect of the different states of stress produced by different combinations of bending and torsion on the fatigue strength of an aluminum alloy, 76S-T61, which was used for aircraft propellers and (2) the effect of different values of mean stress on the fatigue strength of the same alloy under the same states of stress.

The first portion of the investigation is discussed in this paper and the second portion in another paper (43). At the time these tests were started in August, 1942 fatigue tests of aluminum alloys under combined bending and torsion were unknown to the author (although it is now known that tests by Nisihara and Kawamoto (14) had just been published in Japan) and no tests had been reported for combined stress fatigue tests with different values of mean stress superimposed on the alternating stresses. Recently H. J. Gough (18) published results of such tests on steels.

TERMINOLOGY AND NOTATION

State-of-Stress:

The state of stress at a point in a stressed body may be described in terms of nine components of stress acting on three planes passing through the point so long as the planes do not all intersect in the same line. Each of these stress components must be described in terms of its magnitude, sense, and direction. Thus 27 quantities are required for the general description of the state of stress. The complexity of the description may be reduced by selecting orthogonal planes and further reduced by selecting the planes of reference so that the stresses are principal stresses.

Since for purposes of analysis it is highly desirable to be able to express the concept of the state of stress by a single quantity it is proposed that a quantity, to be called the state-of-stress vector, be employed. The state-of-stress vector is the vector sum of the three principal stresses $\sigma_1 > \sigma_2 > \sigma_3$ at a point (Fig. 1). The relation between the state-of-stress vector $\overline{S}$ and the principal stresses may be described by the magnitude of the state of stress vector S, where

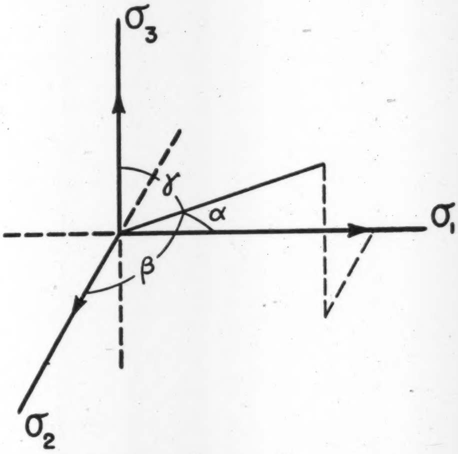


FIG. 1.—State-of-Stress Vector, Illustrating Three Principal Stresses of Unequal Tension.

$$S = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} \ldots\ldots\ldots (1)$$

and the direction cosines

$$l = \cos\alpha = \frac{\sigma_1}{S}, \quad m = \cos\beta = \frac{\sigma_2}{S},$$

$$n = \cos\gamma = \frac{\sigma_3}{S} \ldots\ldots (2)$$

of the angles α, β, and γ between the state-of-stress vector and the three principal stress axes, see Fig. 1.

The limitations imposed by the requirement that a tensile principal stress is a positive vector, a compressive principal stress is a negative vector and that the three principal stresses are related to each other by $\sigma_1 > \sigma_2 > \sigma_3$ cause all possible state-of-stress vectors to be confined within the semi-infinite wedge shown in Fig. 2. The edge of this wedge is along the line $\sigma_1 = \sigma_2 = \sigma_3$ and its planes are defined by the edge line and the positive σ_1-axis on the back side of the wedge and by the edge-line and the negative σ_3-axis on the front side.

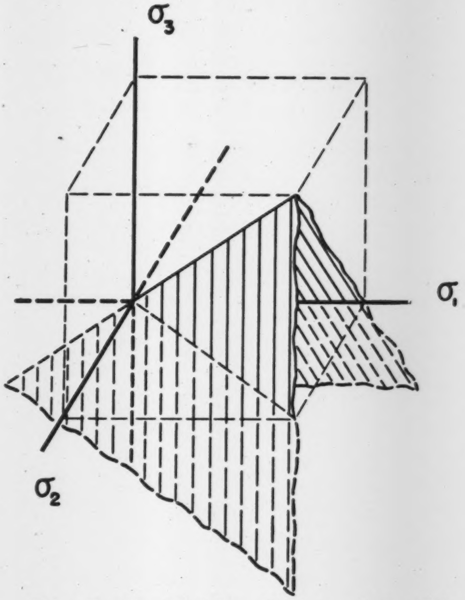


FIG. 2.—Semi-infinite Wedge of Possible State-of-Stress Vectors.

Combined bending and torsion tests permit state-of-stress vectors lying in an area (within the wedge) illustrated in Fig. 3(*a*) and combined axial load and internal pressure in tubes permit state-of-stress vectors lying within the areas illustrated in Fig. 3(*b*). If the axial stress is tension, the state-of-stress vector lies in the horizontal area; if compression, in the vertical area of Fig. 3(*b*).

Fatigue Strength:

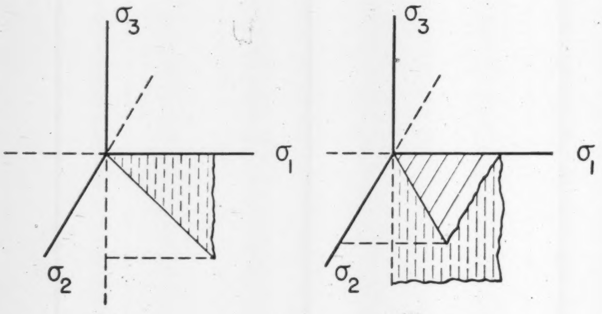
The fatigue strength is defined in this paper as the largest alternating stress amplitude for which the specimen could be expected to withstand a given number of stress cycles at a given mean stress without fracture.

For a discussion of other terms and an introduction to fatigue testing refer to the ASTM Manual on Fatigue Testing (**44**).

The other end of the specimen was fastened by a single bolt to a lever *C* the other end of which was deflected up and down by a connecting rod *D* driven by an adjustable crank *E*.

Adjustment of the crank provided means for varying the amplitude of the stress. The grip was adjustable vertically in a slide *F* to permit selection of any desired mean stress. A dial *G* was mounted on a stiff arm attached to slide *F* so as to indicate the deflection of the lever *C*. A switch *H* was provided to stop the machine when the specimen fractured into two pieces and a counter was provided to indicate the number of cycles.

The arrangement for loading the specimen and the bending and twisting moment arms are illustrated diagrammatically in Fig. 4(*b*). When the angle θ between the axis of the specimen and a line joining the point of loading on the moment arm with the mid-point of the specimen was at 90 deg the mid-point of the specimen was subjected to a twisting couple, no bending moment, and a small vertical shear force (the stresses produced by the latter were negligible for the dimensions employed). On either side of the mid-point there was a bending moment which increased linearly from zero.



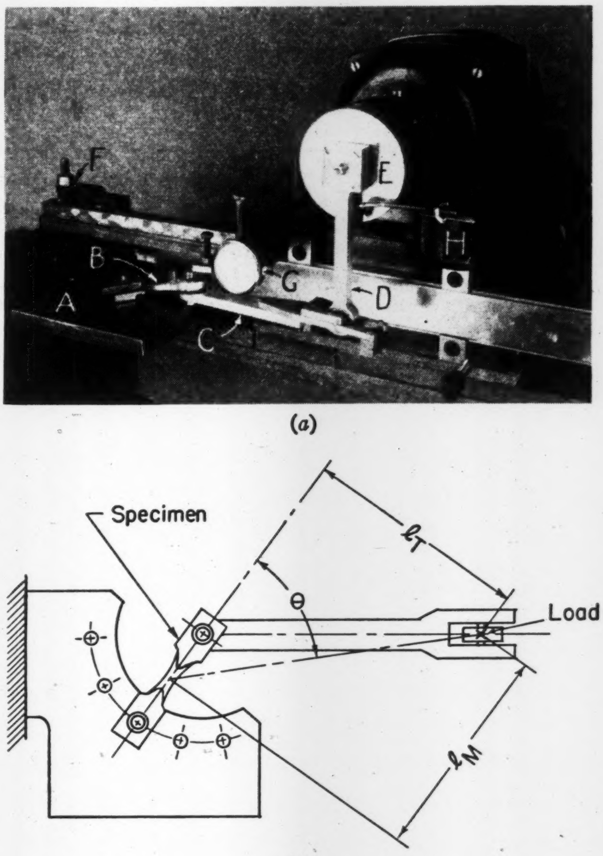
(*a*) (*b*)

FIG. 3.—State-of-Stress Vectors Which Can Be Produced by (*a*) Combined Bending and Torsion (*b*) Combined Axial Load and Internal Pressure in Thin Tubes.

FATIGUE MACHINE FOR COMBINED BENDING AND TORSION

One of the five Krouse fatigue machines of the constant-amplitude-of-deflection type used in this program is shown in Fig. 4(*a*). A special fixture was designed to permit this machine to be used for bending or torsion or a combination of bending and torsion. The apparatus was a revision of that previously constructed for tests of plastics (**45**). It consisted of a plate *A* which was fastened in the grip of the testing machine. One end of the specimen *B* was fastened to this plate in the desired position by means of tapped holes in the plate. The position of attachment depended upon whether the specimen was to be subjected to bending, torsion, or some combination of the two.

When the angle θ was zero the midpoint of the specimen had a bending moment, no twisting moment, and a negligible vertical shear force. At other values of θ combinations of bending and twisting moments were produced.



(a)

(b)

FIG. 4.—Fatigue Machine for Combined Bending and Torsion.
l_M = Bending moment arm.
l_T = Twisting moment arm.

TEST PROCEDURE

Fatigue Tests:

After the specimen had been mounted in the machine with the correct angle θ small loads were applied in increments at the wrist pin (with the connecting rod detached). The resulting deflection was noted on dial *G* and a diagram of the load *versus* deflection was plotted. These loads were kept within the elastic limit of the material to avoid yielding.

From the slope of the load-deflection line the deflection required to produce the desired maximum stress of the fatigue cycle was determined.

In adjusting the testing machine the desired amplitude was first provided while the mean stress was zero. Then the slide *F* was raised with the crank in the upper position until the desired minimum stress was reached. The machine was then started from this position

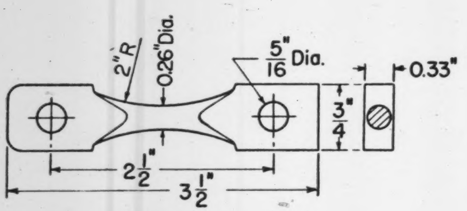


FIG. 5.—Fatigue Specimen.

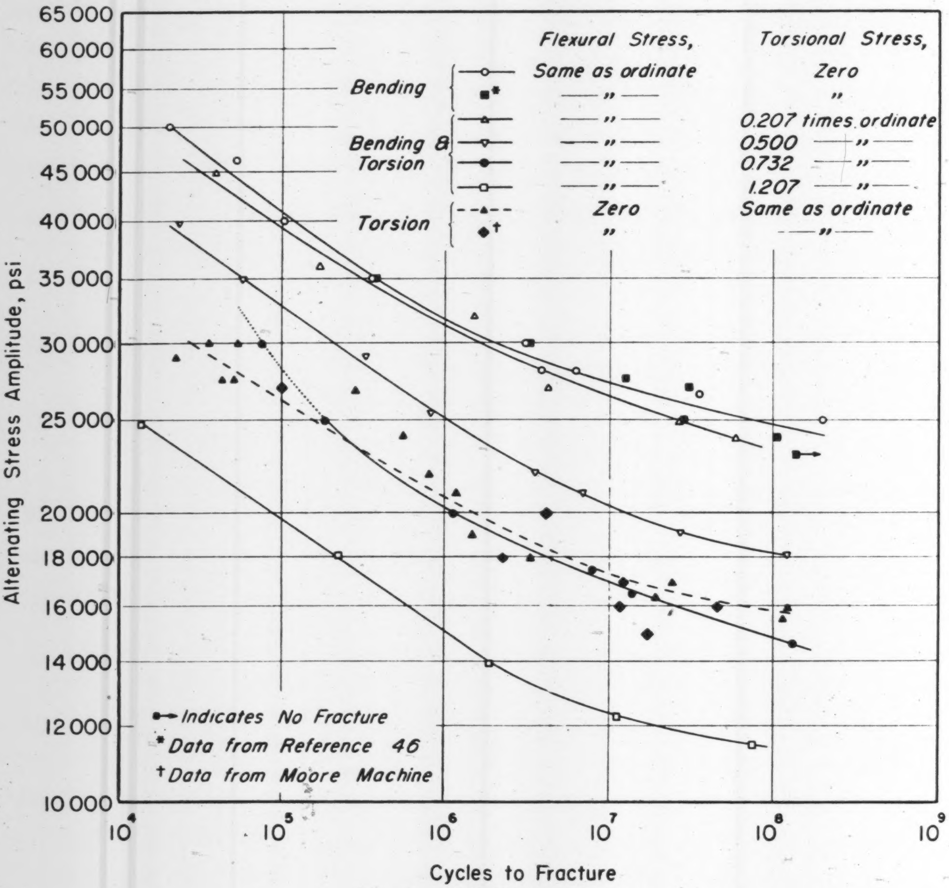


FIG. 6.—*S-N* Diagrams.

so that yielding, if it occurred, always took place under as high rate of straining as possible.

Static Tests.

Static tension tests were performed previously by Dolan (46) on specimens ½ in. in diameter with an Amsler testing machine as described in the reference. Compression tests were performed on specimens ½ in. in diameter and 2 in. long on a beam-weighing testing machine using the same apparatus and technique described in other papers by the author (45, 47) on tests of plastics. Torsion tests of specimens having a 1-in. gage length and a diameter approximately the same as that of the fatigue specimens were performed by means of apparatus and technique described in the previous papers (45, 47).

MATERIAL TESTED

The material was originally designated M68 but now carries the Alcoa numbers 76S-T61. The material, which is used primarily for forging airplane propellers, was supplied by Hamilton Standard Division of United Aircraft Corp. in swaged bars 1 in. in diameter by 12 in. long. Additional information on this material is contained in reports by Dolan (**46–48**). The material tested in this program is of the same heat and lot of alloy tested by Dolan. In fact, many of the specimens were prepared from the remaining portion of the long fatigue specimens employed by him.

TABLE I.—STATIC TESTS.

	Elastic Modulus, psi	Apparent Proportional Limit, psi	Yield Strength, psi		Ultimate Strength, psi	True Fracture Stress, psi	Strain Rate, in. per in., min
			0.05 per cent Offset	0.2 per cent Offset			
TENSION TESTS							
Data as reported previously (46), average of 6 tests..	9.69×10^6	....	64 200	67 200	72 500	....	....
Revised from Ref. 46, Fig. 8, average of 3 tests:							
Normal stress and strain........................	9.66×10^6	51 000	64 000	67 400	73 100	95 000	
Shearing stress and strain........................		25 500	31 500	33 500	36 500	47 500	
COMPRESSION TESTS							
Average of two tests:							
Normal stress and strain........................	10.5×10^6	60 000	67 800	72 300	77 100[a]	....[a]	0.00065
Shearing stress and strain........................		30 000	33 500	35 700	38 500[a]	....[a]	
TORSION TESTS, DATA BASED ON SHEAR STRESS AND STRAIN							
Data as reported previously (46), average of 3 tests							
Specimens 0.56 in. diam., nominal stress........	4.06×10^6		59 500		63 600		
Data from specimen 0.261 in. diam., one test:.....							
Nominal values of stress........................	3.85×10^6	31 000	38 800	44 200	60 800		0.0021
Stresses corrected for yielding..................		27 000	32 600	36 000		45 600	

[a] Load was still increasing; did not fracture.

SPECIMENS

Specimens for the fatigue tests were machined to the dimensions shown in Fig. 5. A procedure was used for the fatigue specimens which minimized vibratory stresses resulting from the machining. The large radius was formed by swinging the compound of the lathe.

Polishing the critical section of the specimens was accomplished by mounting them between centers and rotating them about 700 rpm while polishing the surface with polishing paper wrapped around a $\frac{3}{4}$-in. bar driven through a flexible shaft at 1750 rpm. Behr-Manning polishing paper of the following grits were used in succession: 0, 00, 000. Oil was used in all the polishing and the angle of the polishing bar was altered between grades of paper. Polishing with each grade continued until scratches from the previous operation were removed.

RESULTS

Fatigue Data:

In Fig. 6 are shown the *S-N* diagrams for bending, four combinations of bending and torsion and torsion. These diagrams have log-log coordinates and a vertical scale modulus six times the horizontal. The curves for all diagrams were drawn on separate sheets by inspection before being combined as shown, and represent the average relationship between log alternating-stress and log number-of-cycles.

The ordinates in Fig. 6 represent only one of the two components of stress (flexural and torsional) applied to the specimens. The other component may be obtained by multiplying the given component by the constant shown in the figure since the proportion of bending to torsion was the same in all tests of a series. That is, the state of stress was constant for all tests of a series and also constant at all points in the stress cycle for a given series of tests.

In Fig. 6 are also plotted data reported earlier by Dolan (46) from bending tests of the same material using a specimen with a larger radius. The agreement is satisfactory.

Fatigue tests in torsion are shown in Fig. 6 for two different type machines: the H. F. Moore torsion machine, and the machine described above. Initially it was planned to use the Moore machine for all torsion tests. But, the plan was changed because of the scatter of data and because it was observed that unpredictable static bending stresses could not be avoided in clamping the specimen in the Moore machine. However, the results show that the amount of scatter from the two machines was comparable and the results are in reasonable agreement, as shown. The results obtained from the Moore machine were not considered in drawing the curve nor in the analysis which follows.

Static Tests:

Several static properties measured from tests of this alloy are given in Table I.

The values of stress in the torsion test have been corrected as described elsewhere (42, 43) for the non-linear stress distribution resulting from yielding. Corrected values of yield strength and proportional limit are given in Table I together with the true stress at fracture in tension and in torsion. The latter was calculated on the assumption that the stress on the cross-section of the test bar was constant along any diameter at the ultimate torque. This calculation yielded the result that the true fracture stress was equal to $\frac{3}{4}$ the nominal value regardless of the diameter.

It was observed that the corrected shearing stress from the torsion tests was nearly equal to that from the tension tests at the proportional limit, yield strength and true fracture stress, and nearly equal to that from the compression tests at the proportional limit and yield strength.

For purposes of comparison the yield strengths in tension and compression tests were calculated in terms of shearing stresses at the given values of offset corresponding to shearing strain. That is, for the same value of shearing strain (or offset) in both tension and torsion the normal strain in the tension test equaled the shearing strain in the torsion test divided by $1 + \mu$, where μ is Poisson's ratio. A value of Poisson's ratio of 0.3 was used.

Theories of Failure Under Combined Stress:

Many theories have been proposed as governing yielding or fracture under a single application of combined stress. Several of the same theories have been proposed for fatigue failure, but none has received universal acceptance. Possibly the nature of fatigue, commencing as it does on a small scale at the atomic or crystal level, may in the final analysis make it impossible to define the conditions of failure in terms of the usual concept of stress or strain. However, at present there is no choice but to express these conditions in terms of stress or strain.

All theories which have seemed to hold any promise have been investigated in the present analysis. The list of theories considered is given in Table II with:

TABLE II.—THEORIES OF FAILURE.

Theory	Equation of Limiting Value in Terms of Principal Stresses $\sigma_1 > \sigma_2 > \sigma_3$	Equation for Combined Bending σ and Twisting τ	Required Ratio b/t	Equation Corrected for Anisotropy in Terms of Bending σ, Twisting τ, and b/t
1. Principal stress	σ_1	$\sigma_1 = \frac{1}{2}[\sqrt{\sigma^2 + 4\tau^2} + \sigma]$	1^a	$\sigma_1 = \frac{1}{2}\left[\sqrt{\sigma^2 + 4\left(\frac{b}{t}\right)^2 \tau^2} + \sigma\right]$
2. Principal shear stress	$\tau_1 = \frac{\sigma_1 - \sigma_3}{2}$	$\tau_1 = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$	2	$\tau_1 = \frac{1}{2}\sqrt{\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2}$
3. Principal strain	$\epsilon_1 = \frac{1}{E}[\sigma_1 - \mu(\sigma_2 + \sigma_3)]$	$\epsilon_1 = \frac{1+\mu}{2E}\left[\sqrt{\sigma^2 + 4\tau^2} + \frac{1-\mu}{1+\mu}\sigma\right]$	$1 + \mu^a$	$\epsilon_1 = \frac{1+\mu}{2E}\left[\sqrt{\sigma^2 + \left(\frac{2b}{t(1+\mu)}\right)^2 \tau^2} + \frac{1-\mu}{1+\mu}\sigma\right]$
4. Principal shear strain	$\gamma_1 = \frac{1+\mu}{E}(\sigma_1 - \sigma_3)$	$\gamma_1 = \frac{1+\mu}{E}\sqrt{\sigma^2 + 4\tau^2}$	2	$\gamma_1 = \frac{1+\mu}{E}\sqrt{\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2}$
5. Energy of distortion	$W_D = \frac{1+\mu}{6E}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]$	$W_D = \frac{1+\mu}{3E}[\sigma^2 + 3\tau^2]$	$\sqrt{3}$	$W_D = \frac{1+\mu}{3E}\left[\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2\right]$
6. Octahedral shear stress	$\tau_0 = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$	$\tau_0 = \frac{\sqrt{2}}{3}\sqrt{\sigma^2 + 3\tau^2}$	$\sqrt{3}$	$\tau_0 = \frac{\sqrt{2}}{3}\sqrt{\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2}$
7. Total energy of Deformation	$W = \frac{1}{2E}[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)]$	$W = \frac{1}{2E}[\sigma^2 + 2(1+\mu)\tau^2]$	$\sqrt{2(1+\mu)}$	$W = \frac{1}{2E}\left[\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2\right]$
8. Magnitude of state-of-stress vector	$S = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}$	$S = \sqrt{\sigma^2 + 2\tau^2}$	$\sqrt{2}^a$	$S = \sqrt{\sigma^2 + \left(\frac{b}{t}\right)^2 \tau^2}$
9. Complete Guest's law	$t = \frac{1}{2}\left[\sigma_1 - \sigma_3 + \left(\frac{2t}{b} - 1\right)(\sigma_1 + \sigma_3)\right]$	$t = \frac{1}{2}\left[\sqrt{\sigma^2 + 4\tau^2} + \left(\frac{2t}{b} - 1\right)\sigma\right]$	Any	No Correction Needed
10. Ellipse quadrant		$1 = \left(\frac{\tau}{t}\right)^2 + \left(\frac{\sigma}{b}\right)^2$	Any	No Correction Needed
11. Ellipse arc		$1 = \left(\frac{\tau}{t}\right)^2 + \left(\frac{b}{t} - 1\right)\left(\frac{\sigma}{b}\right)^2 + \left(2 - \frac{b}{t}\right)\frac{\sigma}{b}$	Any	No Correction Needed

E is Young's modulus, μ is Poisson's ratio, and b and t are the fatigue strength in bending and torsion, respectively.

[a] Required b/t less than actual value (1.55).

the corresponding equation expressed in terms of the principal stresses; and the equation as simplified for the case of combined bending and torsion.

The latter equation is expressed in terms of the flexural stress σ and torsional stress τ.

In addition to the well known theories the empirical equations proposed by Gough (the ellipse arc and ellipse quadrant) have been tried, together with two theories not previously considered. One of these is that fatigue failure may occur when a limiting magnitude of the state-of-stress vector is reached. No physical significance is attached to this theory as it is not much more than an empirical equation. The other theory is based on the suggestions (40) that anisotropy may be an important factor in combined-stress fatigue tests and that a correction for anisotropy may be employed in results of combined bending and torsion fatigue. This correction can be applied to each of the rational theories of failure (41) with the results given in the last column of Table II. It was observed that this correction for anisotropy reduced six of the theories to the same form. The only differences were: the coefficient, and the fact that the energy equations were squared. In the analysis which follows reference will be made only to the principal shear stress corrected for anisotropy.

These observations suggest that the influence of anisotropy should be studied more thoroughly, and that combined bending and torsion fatigue tests are inadequate to distinguish among six of the theories if anisotropy is present.

Effect of State of Stress:

By use of (1) the equations given in Table II, (2) the relation between σ and τ for the different states of stress, and (3) the fatigue strengths, the values of the quantity corresponding to the fatigue strength were computed for each of the theories.

In making the computations the value of the modulus of elasticity employed was 9.69×10^6 psi as reported previously (46) from tension tests. A larger value would have been justified by the compression test data subsequently obtained. A value of 0.3 was used for Poisson's ratio. No direct measurements of Poisson's ratio are available for 76S-T61 aluminum alloy. Poisson's ratio as calculated from the average of the tension and compression modulus and the shearing modulus from the torsion test was 0.31. Available data (49) on 75S-T6 aluminum alloy indicate a value of 0.33.

The values of b and t used in making the computations for Guest's law, the ellipse quadrant, and the ellipse arc were the values of the fatigue strength in bending and in torsion respectively at the number of cycles considered.

The value of the alternating component of the quantity at zero mean stress was plotted as a function of the state of stress for each of the theories, as illustrated in Fig. 7 for four of the theories. The measure used for the state of stress was the last direction cosine of the state-of-stress vector:

$$n = \sigma_3/S \qquad (3)$$

For the range of states-of-stress employed in this investigation only one direction cosine is necessary to identify the state of stress, since all the state-of-stress vectors lie in one plane. The direction cosine n was chosen because it spaced the test values of state-of-stress more evenly than the direction cosine l.

On a diagram of the type shown in Fig. 7 exact agreement with the theory would be represented by straight horizontal lines. A logarithmic ordinate was used in all of these diagrams because the percentage change in a quantity is

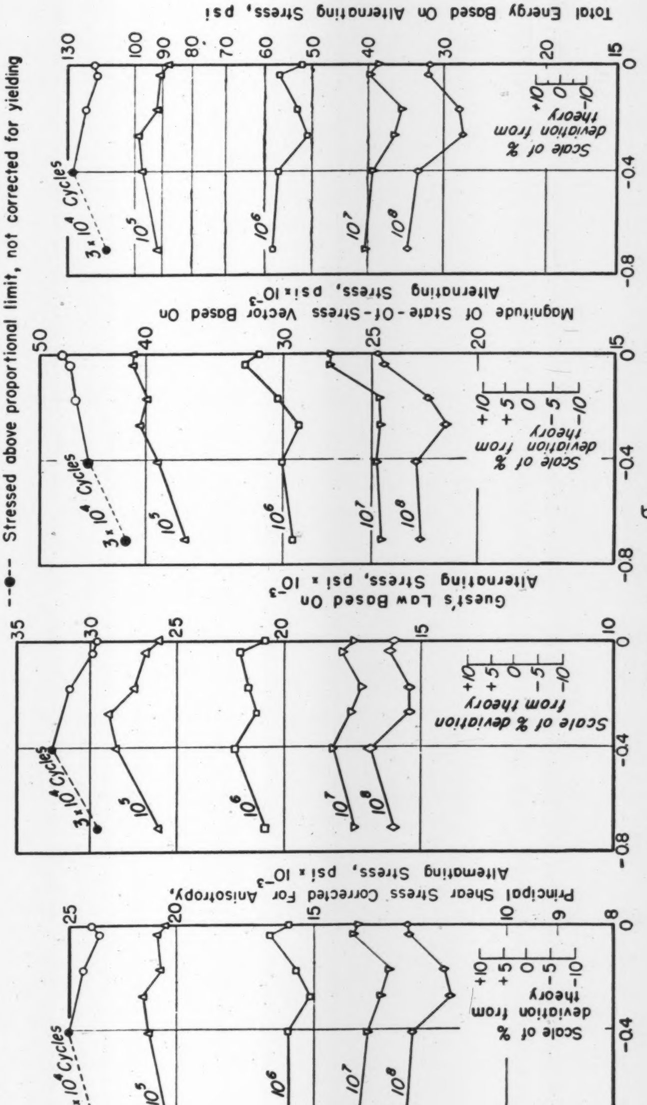


FIG. 7.—Theories *versus* State-of-Stress.

represented by the same linear distance on a logarithmic scale regardless of the magnitude of the quantity. Thus logarithmic diagrams permit direct comparison (between the various curves) of the relative deviation of the test values from the theory. A scale is inset on each of the diagrams to aid in evaluating the correspondence between theory and experiment. An examination of these diagrams indicated the following order of merit (as indicated by the present data) for the several theories and empirical equations:

1. Principal shear stress corrected for anisotropy
2. Guest's law (complete)
3. Largest principal strain corrected for anisotropy
4. Ellipse quadrant
5. Magnitude of state-of-stress vector
6. Ellipse arc
7. Total strain energy
8. Octahedral shear stress
9. Largest principal stress corrected for anisotropy
10. Largest principal strain
11. Energy of distortion
12. Largest principal shear stress
13. Largest principal shear strain
14. Largest principal stress

Since a complete statistical analysis of the data for these theories did not seem practical the above order of merit was determined by drawing the straight line which best represented the data in diagrams such as Fig. 7 and using the slopes of these lines and the maximum deviations from the lines as guides in arriving at an opinion.

The following observations were made: there was not much choice between the first two theories; the fourth is the same as the square of the first (40); the data deviated considerably from the predictions of theories 10 through 14; and there was no difference between the predictions of theories 12 and 13.

Of the 14 theories listed above the fourth and sixth are empirical and the fifth is nearly so. The energy theories, 7 and 11, do not seem reasonable (41, 42) as possible theories of failure under fatigue since energy is a scalar quantity whereas fatigue is known to originate at the crystallographic level where orientation of stress relative to the crystal lattice probably is an important factor. Also the octahedral shear stress, 8, is of doubtful significance as a theory of fatigue failure since this shear stress is less than the maximum shear stress.

Thus the theories which seem to hold the most promise are: (*a*) the principal shear stress corrected for anisotropy, (*b*) the complete Guest law, and (*c*) the largest principal strain corrected for anisotropy.

Additional Studies:

A similar test program has been completed on two additional materials (SAE 4340 steel and 25S-T aluminum alloy) using improved testing machines and technique, a larger number of tests per *S-N* diagram and tests at different mean stresses for several combinations of bending and twisting. These data are now being analyzed and will be reported later.

It seems desirable to study fatigue under other states of stress where differentiation between theories will be more positive. The role of anisotropy should also be given additional study. A start has been made by testing miniature specimens cut from the bars of 76S-T61 aluminum alloy, studied in the present investigation, at different orientations.

CONCLUSIONS

1. As indicated in the review of the status of the problem, the available test data under other types of combined loadings than bending and torsion do not eliminate the limiting shear stress as a possible theory of fatigue failure under combined stress.

2. If anisotropy is considered as affecting the results then fatigue tests under combined bending and torsion are inadequate to differentiate between six of the theories. Tests at other states of stress are needed to separate these theories and to test the applicability of the theories over a wider range of states of stress.

3. A more thorough study of the influence of anisotropy on fatigue under combined stress is needed.

4. The proposed theories and empirical equations governing fatigue failure under combined stresses which best represented the test data are as follows in order of merit: (*a*) principal shear stress (principal shear strain, etc.) corrected for anisotropy, (*b*) complete Guest law, (*c*) largest principal strain corrected for anisotropy, (*d*) ellipse quadrant, (*e*) magnitude of state-of-stress vector, (*f*) ellipse arc, (*g*) total strain energy, etc.

5. In view of the inconsistencies and limitations of several of the theories as discussed above the only ones of the rational theories which seem to hold much promise are as follows: (*a*) principal shear stress corrected for anisotropy, (*b*) complete Guest law, and (*c*) largest principal strain corrected for anisotropy.

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DISCUSSION

MR. J. T. RANSOM.[1]—I have several points which may be of interest to the author and others working in this field. First, I should like to ask a question concerning the testing machine used in this investigation. In our laboratory we recently started to carry out fatigue tests under combined bending and torsion using a similar cam-operated testing machine. In order to check accurately the stresses in the specimen, we cemented SR-4 wire strain gages to the test section and used an Ellis BA-11 to measure the static and dynamic stresses. We discovered that the bending stresses induced by a given cam setting were about 50 per cent greater at 1800 cpm than when the cam was turned slowly by hand. By further investigation we surmised that the natural frequency of the specimen-loading arm system was close enough to the 1800 cpm to give considerable resonance effect. Hence, in machines of this type, it may not be sufficient to calibrate the machine statically for determination of dynamic stresses. Not only may the stresses be incorrect, but the ratio of the principal stresses may not be what was expected. Also, the natural frequency, and therefore the errors from resonance, will change with angular setting of the specimen. I should like to ask Mr. Findley whether he actually checked the dynamic stresses or has other information to indicate that errors due to resonance effects did not influence his results.

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For my second point, I should like to question why we must attempt to make a single theory of combined stress fit all combinations of principal stresses in anisotropic materials. At duPont we have reasoned that a study of the mechanism of the initiation of the fatigue crack would help to select the theory of combined stress. For example, if the crack forms by a shearing mechanism, then a maximum principal stress or strain theory is illogical; and conversely, if the crack begins by a tensile mechanism, then a shear theory is untenable. Our method of studying this mechanism will be described more fully in a paper now in preparation. As a result of this type of study we have found that the mechanism of failure does change, depending upon the relative magnitudes of the principal stresses and their directions with respect to the forging fiber. For example, in one heat of SAE 4340 steel which possessed a very pronounced anisotropy, torsion specimens could be made to fail by either a tensile or a shear mechanism depending upon the orientation of the specimen in the forging. When a tensile mechanism operated, failure was parallel to the forging direction, and the endurance limit, expressed in terms of the tensile principal stress, correlated with the transverse endurance limit in bending. However, when a shear mechanism operated, although the crack was still parallel to the forging direction, the endurance limit, expressed in terms of shear stress, correlated fairly well with the longitudinal endurance limit. It would appear that if useful combined stress theories are to be developed for anisotropic materials, not only the ratio of the principal stresses but also their directions with respect to the anisotropy must be considered. Under these conditions, a single theory may not suffice; the service application will have to be analyzed for these same factors and the appropriate theory selected.

My last point concerns a complication which apparently has been neglected in combined stress studies. This is the variable size effect or shape effect—whichever you choose to call it—in the various orientations of the torsion-bending specimen. For example, at the extreme of plain bending, only the top and bottom fibers are stressed to the maximum, while at the other extreme of plain torsion, the entire surface area in the test section is equally stressed. Thus, the volume of material under test actually varies from practically nothing up to a fair quantity. The size effect is known to be very large in the region of small sizes. Hence, we believe that this is another factor which creates difficulties in correlating bending and torsion tests through use of combined stress theories based on ideal conditions.

MR. R. E. PETERSON.[2]—I should like to make a few comments regarding the anisotropy. If the maximum shear theory governs, there should be a ratio of torsional to axial (bending) endurance limits of one-half. Actually, the ratio tends to be higher than one-half. One might say that this departure means that either the torsional endurance limit is higher than it should be, or the axial (bending) limit is lower. Most axial or bending test specimens are taken along the direction of the bar, which is the strongest possible orientation.

If anisotropy were the only consideration, one would expect that, if anything, the torsional values might be lowered relative to the axial (bending), resulting in a ratio less than one-half instead of more than one-half, as usually found. The average of such ratios for ductile materials is approximately $1/\sqrt{3}$ or 0.577, which is in accordance with the Mises criterion. This of course does not "prove" the applicability of this criterion. My comment is intended to point out that it does not seem likely that the departure of the above-mentioned ratio from one-half (maximum shear theory) is due to anisotropy.

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MR. W. N. FINDLEY (*author's closure*).—The valuable comments of the discussors are appreciated. Mr. Ransom's comment concerning calibration is pertinent. Machines of this type do need dynamic calibration, especially if a natural frequency of the vibrating parts is near the operating speed of the machine. In the present system the natural frequencies were much higher than the operating frequency. While the equipment used for the present tests was not calibrated dynamically, the dynamic characteristics of similar equipment which was developed later[3, 4] to effect certain improvements was studied thoroughly. A dynamic analysis of the vibration of the machine was made[4] and dynamic calibrations were made both by mechanical measurements[3] and by wire strain gages. The apparatus and technique developed for the latter calibration has been described by Worley.[5]

It is of interest to note that the dynamic calibrations by both mechanical and electrical techniques were in close agreement. The dynamic stress was from 1 to 5 per cent higher than the static stress, depending on the test conditions and bearings of the particular machine. The 50 per cent higher dynamic stress found by Mr. Ransom for his machine is rather surprising.

Mr. Ransom has asked why we must attempt to make a single theory of combined stress fit all combinations. It seems to me that the inception of a phenomenon that starts at the level of interatomic forces, as fatigue appears to do, must be governed by interatomic relations. Thus one basic law, involving several parameters perhaps, would seem to be applicable for the inception of fatigue.

However, in fatigue testing we observe the gross effect not only of the inception of a fatigue crack but its propagation. Thus a law describing the ultimate fatigue failure must include those several factors that control propagation of cracks. Thus there may be several terms in a complete law of fatigue failure under combined stress. For some conditions one term may predominate; for other conditions, another term may predominate so that the resulting gross effects may appear to be so different as to seem to result from different causes.

Concerning the question of mode of crack formation, the full report[6] on this investigation contains a description of the observed modes of crack formation and propagation. My interpretation of what was observed was that fatigue cracks in every case started as slip displacements followed by shearing cracks. Under certain conditions described in the report, these cracks propagated as shear cracks for most or all of the fatigue process. Under other conditions the initial shear cracks changed in early stages to propagation by tension-separation cracks. Thus present data indicate that the mechanism of initiation of fatigue cracks was the same for all the states of stress studied but that propagation of cracks was by two different mechanisms, depending on the state of stress, stress level, and mean stress.

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[6] W. N. Findley, "Combined-Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," Report to the National Advisory Committee for Aeronautics, July, 1951.

I agree with Mr. Ransom's observations that useful combined stress theories for anisotropic materials should consider the relative orientation between the material and the stresses and that the "variable shape effect" may affect the results of combined bending and torsion fatigue tests. If the variable shape effect were eliminated by using combined axial load and torsion instead of bending and torsion, however, the stress gradient effect would be introduced.

I am in agreement with Mr. Peterson's observation that, if anisotropy were the only consideration, one would expect the torsional values to be lowered relative to the bending values instead of higher, as observed. However, the actual aniostropy of the material tested was not known. We are now making tests to learn something about the anisotropy of this alloy, using the apparatus developed for this purpose and described in another paper.[4]

Other factors probably also exert an influence on the results of fatigue under combined stress. In the full report[6] it was suggested that mode and rate of crack propagation may have influenced the relation between results of bending and torsion fatigue tests—especially since two modes of crack propagation were found.

EFFECT OF TENSILE AND COMPRESSIVE FATIGUE STRESS ON CREEP, RUPTURE, AND DUCTILITY PROPERTIES OF TEMPERATURE-RESISTANT MATERIALS*

By B. J. Lazan[1] and E. Westberg[2]

Synopsis

Newly developed grips and machine improvements are described for fatigue loading under axial stress (tension-compression) under various combinations of mean and alternating stress. Dynamic creep, rupture, and ductility data are reported on N-155, S-590, and Vitallium at 1350 and 1500 F under axial stress combinations from static tension to reversed loading. Stress range diagrams (alternating stress *versus* mean stress) are presented to indicate the stress combination which will produce rupture and various degrees of creep in from 5 to 1500 hr. The general characteristics of these diagrams are discussed. Elongation data are analyzed in terms of alternating-to-mean stress ratio and stress magnitude, and it is shown that both are significant variables. Elongation up to the start of the third stage of creep is also analyzed in terms of stress ratio and stress magnitude, and only stress magnitude was found to be significant. The implications of these findings are discussed.

Present-day developments in new and improved devices operating at increasingly higher temperature have imposed challenging problems on both the metallurgist and machine designer. One of these problems is the evaluation and interpretation of the mechanical properties of materials at elevated temperatures, particularly under cyclic stress. As more data on service failures of parts exposed to elevated temperatures are accumulated and analyses undertaken (**1**),[3] the increasing importance of cyclic stress as a cause for service failure becomes apparent.

The work reported in this paper represents a continuation and extension of earlier research (**2, 4**) on the effect of various combinations of static and alternating direct stress on the creep, rupture, elongation, and other properties of temperature-resistant materials at high temperature. In the earlier work, fatigue stress in the tension range only was investigated, whereas in this program the stress ratios A[4] in the range from zero (static test) to infinity (reversed stress fatigue test) are studied.

Testing Equipment

The basic testing machines used in this program are the same as described previously (**2**) except for changes which increased the capacity of the machines to 5000 ± 5000 lb. Alternating force is imposed by a special centrifugal force type oscillator, and static preload is applied by calibrated springs and maintained constant by an automatic follow up system. Creep is measured with a special micrometer microscope assembly which utilizes stroboscopic light to "fix" for measuring purposes the platinum targets attached to the test specimens. A photograph of this dynamic creep and rupture machine with the furnace, creep-measuring microscopes, and an extra tension-compression fatigue grip is shown in Fig. 1.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 855.

[4] Stress ratio A is the ratio of the alternating stress to the mean stress during the stress cycle (see Reference **2**).

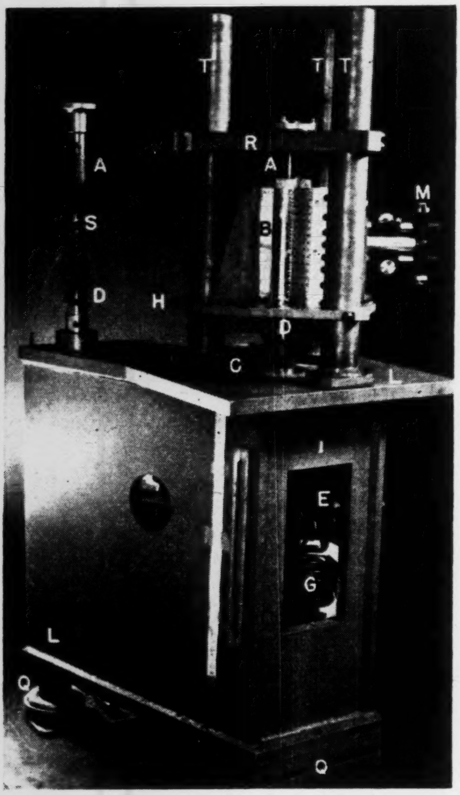


FIG. 1.—Dynamic Creep and Rupture Machine.

The production and maintenance of a uniform stress distribution in direct stress fatigue specimens constitutes a most important task. Very small errors in alignment in the specimen-grip assembly, for example, may result in very serious extraneous bending stress which may seriously affect the reliability of the test data. Consequently, particular emphasis was placed in this work on procuring and maintaining uniform stress distribution in the test specimen, and special grips were developed for this purpose.

A schematic diagram of the reversed stress grips is shown in Fig. 2. The upper stationary platen *R* is the same as shown in Fig. 1, and *B* is the reciprocating platen attached to the centrifugal force cage *E*. Two nuts, *K* and *L*, threaded on each end of test specimen *S*, are clamped between outer tubes (*A* for the upper grip and *D* for the lower grip) and inner tubes *G*. The clamping force is exerted by screws *C* which apply the load through the belleville springs *H*. The function of springs *H* is to maintain reasonable constant preload force in the gripping nuts at all times, even under differential expansion and other influences which may tend to affect tightness. The upper tube *A* is rigidly attached to the upper crosshead *R*, being locked in place between three screws *Y* and three cap screws *Z*. The lower outer tube *D* is attached to the reciprocating part *B* by a threaded ring *F*, which is removable in order to keep the lower end of the specimen-grip assembly smaller than the inside diameter of the furnace for ease in setting up the test. All grip parts are made rigid in order to minimize stress nonuniformity in the test specimen and yet have relatively small cross-sectional area to minimize heat transfer for improved temperature uniformity along the test-length of the specimen.

To set up a test, the specimen-grip assembly is made to run true on centers by preferential tightening of screws *C* and *W*. Thus, only standard tolerance is required for the specimen and mating

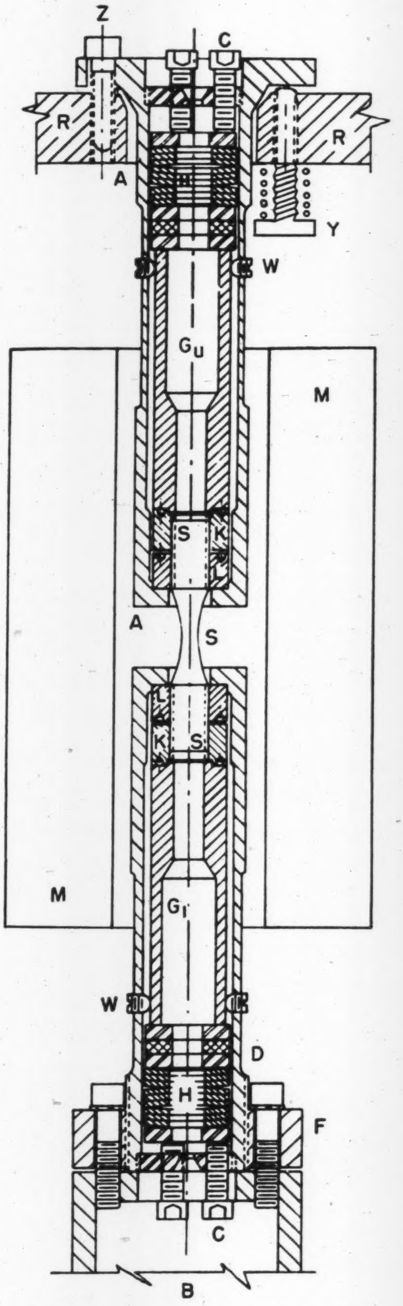
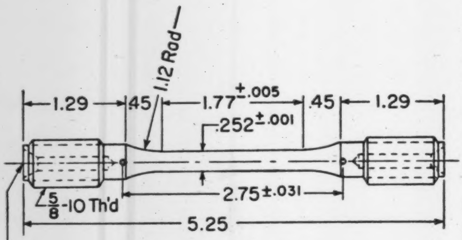


FIG. 2.—Grip-Specimen Assembly in Reversed Stress Fatigue Testing.

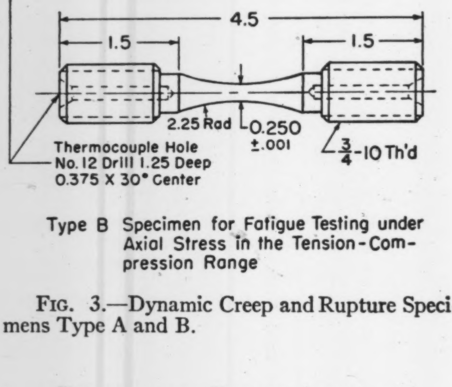
threads. Furthermore, the specimen threaded connections are preloaded by screws *C* to avoid excessive motion, fretting, and "freezing." The assembly is then inserted downward through the furnace, ring *F* is threaded onto the lower end of *D*, and the whole assembly is rigidly locked to the lower head with the screws shown (top end free). The specimen-grip assembly is next bolted to the lower grip and allowed to attain the testing temperature, the upper end of the grip assembly being allowed to expand freely during this period. Set-screws *Y* are then made to contact the lower surface of the flange at the top of *A*, an electrical contactor being used for this operation to avoid imposing undesired initial stress in the specimen. Finally, cap screws *Z* are tightened, thus rigidly locking the flange to the upper crosshead *R*.

The production of consistent and significant direct-stress fatigue data requires that bending stress be avoided during: (*a*) clamping of specimen-grip assembly in fatigue machine, (*b*) application of preload, and (*c*) application of alternating force. The presence and magnitude of each of these types of undesired bending were determined by direct measurement of strain on the test section with six SR-4 wire resistance gages. The early unrefined grips produced up to 25 per cent nonuniformity in stress distribution during clamping as well as during the application of alternating stress. As a result of stress distribution studies and vibration analyses made with a cathode ray oscilloscope, several corrective steps were taken to improve the grips. This led to the grip design and setting-up procedure described previously, in which the clamping stress is negligible and the test stress distribution on the cross section is uniform to within 4 per cent.

Careful calibration was also undertaken of alternating force produced by the machine, three different methods of analyses being used. Calibration data determined by all three methods (two experimental and one theoretical) fell within a ±3 per cent scatter band, an accuracy considered entirely adequate for fatigue work. Description of these calibration methods is outside the scope of this paper.



Type A Specimen for Creep and Rupture Testing under Axial Fatigue Stress in Tension Range



Type B Specimen for Fatigue Testing under Axial Stress in the Tension-Compression Range

FIG. 3.—Dynamic Creep and Rupture Specimens Type A and B.

DESIGN AND PREPARATION OF TEST SPECIMENS

The two different types of test specimens shown in Fig. 3 were used in this project, the test section being ¼-in. diameter in both cases. In general, test specimen type A was used for stress ratios A of 0, 0.25, and 0.67, and type B specimen for ratios of 1.64 and infinity.

The straight sectioned type A specimen was used for the lower stress ratios so that both dynamic creep as well as rupture and fatigue properties could be determined. The simple fillet type B specimen was used at the higher stress ratios, where creep properties are comparatively unimportant (2), because the internal heating due to hysteresis damping (5) is less serious in a small test-volume specimen of type B than in a larger test-volume specimen of type A. However, as discussed later, even in the type B specimens enough internal heat was generated to increase the specimen temperature by 150 F in some tests. A few check tests at a stress ratio of A = 0.67 indicated that rupture data procured on the type B specimens are in agreement with data on type A specimens.

All specimens were longitudinally polished by an abrasive belt method. Specimens of Vitallium and S-590 were machined and finished in a contour block belt polisher as explained in reference (2), and the N-155 specimens were prepared by a somewhat similar method by the University of Michigan (3).

TEST MATERIALS

Data on the following three test materials are reported in this paper:

(*a*) N-155, Universal Cyclops Heat A-1726, water quenched from 2200 F, aged at 1400 F for 16 hr, and air cooled.

(*b*) S-590, Allegheny Ludlum Heat 42189, water quenched from 2250 F, aged at 1400 F for 16 hr, and furnace cooled.

(*c*) Vitallium, Haynes Stellite Heat 573, precision cast, aged at 1350 F for 50 hr and furnace cooled.

Additional metallurgical details and photomicrographs are given in reference (2) for the last two materials and in reference (3) for N-155.

TEST DATA AND DISCUSSION

The behavior of N-155 shall be discussed first. The type of dynamic creep and rupture data procured at the lower stress ratios are shown in Figs. 4 and 5.

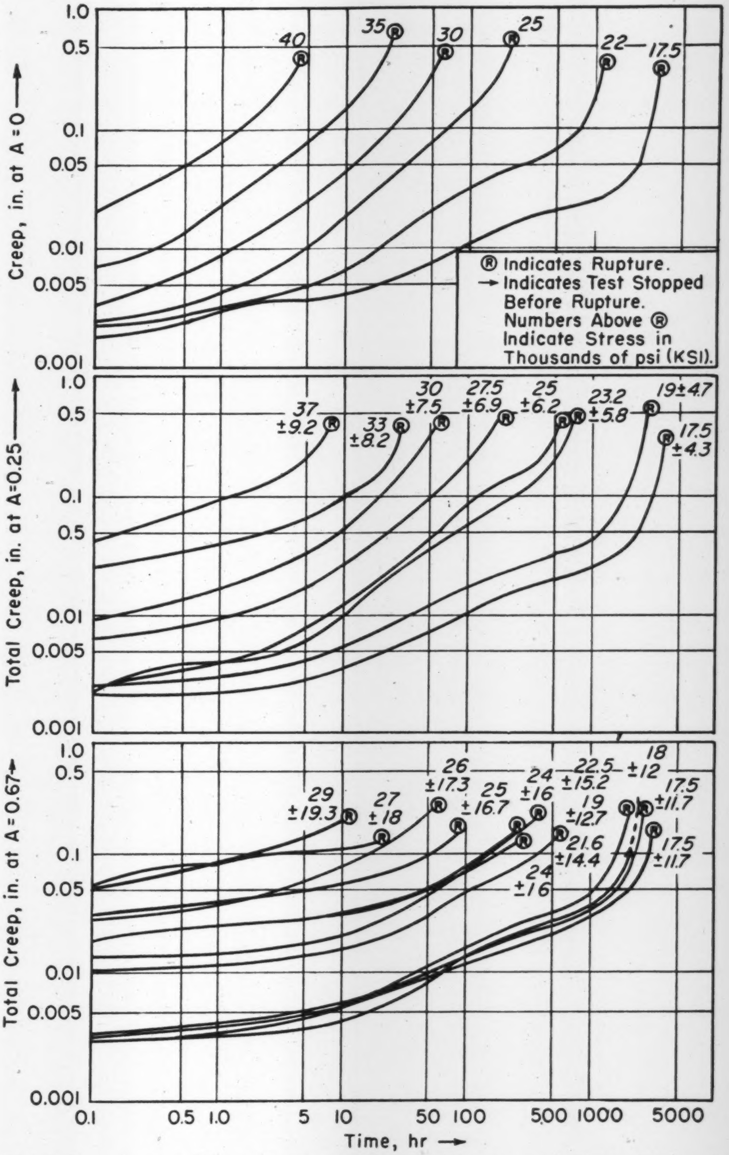


FIG. 4.—Total Creep *versus* Time Curves at Various Stresses and Stress Ratios for N-155 at 1350 F.

At high stress ratios, where dynamic creep became relatively unimportant (2), only time to rupture and elongation were determined. Approximately seven tests were performed at each of five stress ratios *A* at stress levels which cause failure in from approximately 1 to 5000 hr.

The total elongation after fracture was measured for each specimen, and both the "uncorrected" and "corrected" elongation were determined. The uncorrected elongation was determined in the usual way from measurements of the length of the broken specimens matched at the fractured section. The corrected elongation was determined by subtracting the length of the maximum surface opening

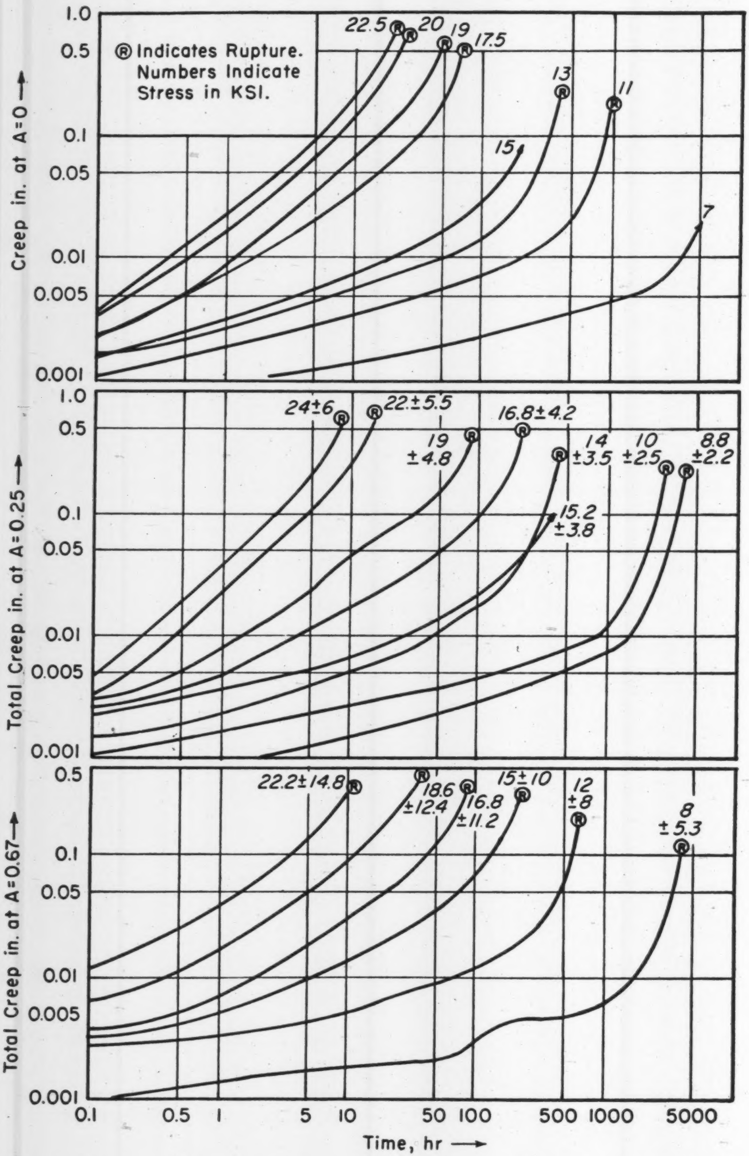


FIG. 5.—Total Creep *versus* Time Curves at Various Stresses and Stress Ratios for N-155 at 1500 F.

at the properly matched fracture section. This surface opening correction is intended to eliminate purely localized deformation which occurs during the final separation at the fracture. At low stress ratios this correction is generally very small whereas at high stress ratios it generally is quite significant.

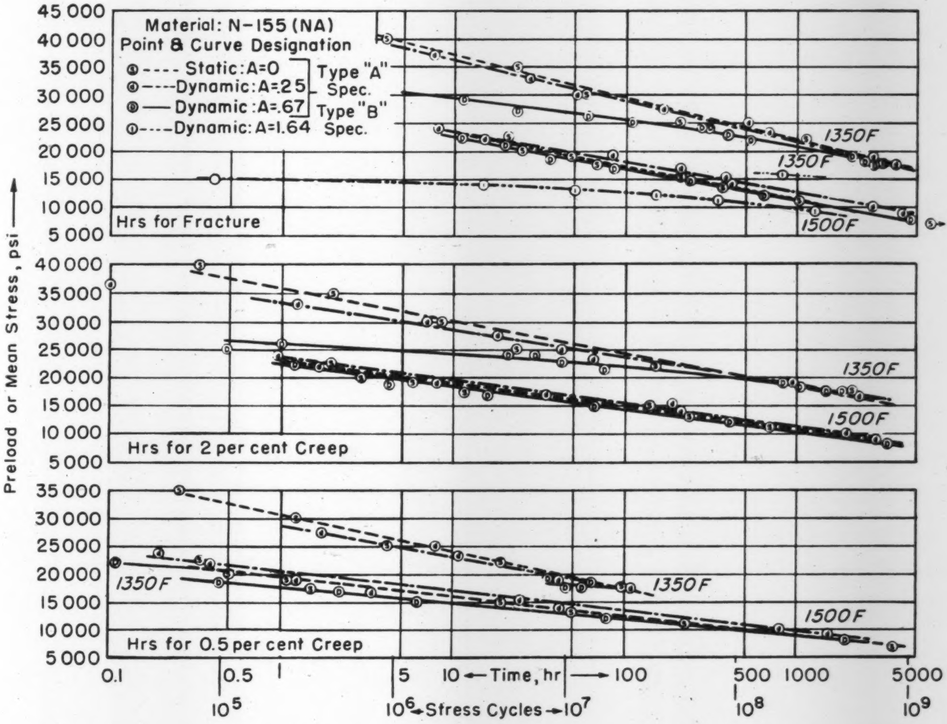


FIG. 6.—Time to Rupture, 0.5 per cent and 2 per cent Creep *versus* Mean Stress During the Stress Cycle for N-155 at 1350 and 1500 F.

In order to determine the per cent elongation from total elongation, the equivalent test section length of each specimen type must of course be known. For specimen type A shown in Fig. 3 the effective gage length was calculated to be 2 in. (2). For specimen type B which has no straight test section, the effective gage length was determined experimentally from elongation data procured under identical conditions on both type A and B specimens. It is recognized that this method of determining the equivalent length of the type B specimen is approximate since the constant determined experimentally from comparative tests is probably somewhat dependent on stress magnitude and stress ratio (since creep is probably not expressible as a function of stress to some fixed exponent n). However, it is believed that this approach is sufficiently accurate to reveal the significant ductility trends discussed later.

Each of the static and dynamic creep curves shown in Fig. 4 is based on approximately 25 experimental points with relatively little scatter. The final reading taken prior to rupture is shown by the symbol (R), which of course may be considerably less than the total elongation since in many cases this reading preceded fracture by several hours. The creep data shown in Fig. 4 are plotted within log-log coordinates to enable including the creep-time relationship up to failure and yet not condense the first part of the curve beyond recognition and use. Being a log-log plot, the customary three stages of creep are not of course recognizable.

Referring to Figs. 4 and 5 it may be observed that at 1350 F the slope in the log creep *versus* log time curves is generally flatter at higher stress ratios, but otherwise the shapes of the curves for equal life are quite similar. At 1500 F the increasing stress ratio does not appear to affect significantly the slope of the log-log curves. Other observations regarding the effects of stress ratio and stress magnitude will be more apparent from derived and reduced curves discussed below.

In order to reveal more clearly the trends in creep and rupture behavior with temperature, stress, and stress ratio, the data obtainable from Figs. 4 and 5 are replotted in Fig. 6 on a mean stress basis. These curves show the hours for rupture, and hours for 2 and 0.5 per cent creep for various stress ratios A as a function of mean stress. Also shown along the abscissa besides the time scale are numbers of stress cycles (machine operates at 3600 rpm). These diagrams include the data on type A specimen at stress ratios of 0, 0.25, and 0.67 and the fatigue strength of type B specimens at the stress ratio of 1.64. Reversed stress fatigue data (mean stress equals zero) cannot of course be shown in this diagram.

A significant observation apparent from Fig. 6 is that the large stress ratio curves ($A = 0.67$ and 1.64) display a smaller semilogarithmic slope than the small stress ratio curves ($A = 0$ and 0.25). This difference in slope, which is larger at 1500 than at 1350 F, means that even though the allowable mean stress for short life is considerably smaller at high stress ratios than at low stress ratios, the allowable mean stress for long life (say in the region of 2000 hr) is quite independent of stress ratio in the range from 0 to 1.64 at 1500 F and from 0 to 0.67 at 1350 F. The same observations may be made regarding creep. These observations will be discussed further in connection with the stress range diagrams to be presented.

Diagrams similar to Fig. 6 were also plotted on the basis of maximum or crest stress so that the reversed stress data (stress ratio $A = \infty$) could be included. These diagrams, not included in this paper, also show that the high stress ratio curves have smaller slope than those at low stress ratios, the curves at $A = \infty$ being practically horizontal. Considering maximum stress as a criterion, the allowable stress for *long life* increases with increasing stress ratio. The same is true for *short life* for the stress ratios of 0, 0.25, and 0.67. However, the allowable maximum stress for *short life* at $A = 1.64$ and $A = \infty$ is substantially less than that for the smaller stress ratios.

In general the slope trends discussed above are associable with the primary cause of failure. At small stress ratios where creep and stress rupture effects predominate, the slopes of these curves are rather large. However, at high stress ratios where fatigue becomes important the slopes become increasingly flat. It should also be mentioned that the S-N fatigue curves for the high stress ratios of $A = 1.64$ and ∞ do not display an S-N knee even up to 3×10^8 cycles. Therefore, a fatigue limit does not appear to exist under these conditions.

Of the various types of diagrams presented to show rupture and creep data the stress range diagrams shown in Fig. 7 are probably the most concise and revealing. These diagrams show the combinations of static preload and alternating stress at 1350 and 1500 F which result in rupture and 2 per cent and 0.5 per cent creep in 5, 15, 50, 150, 500, and 1500 hr.

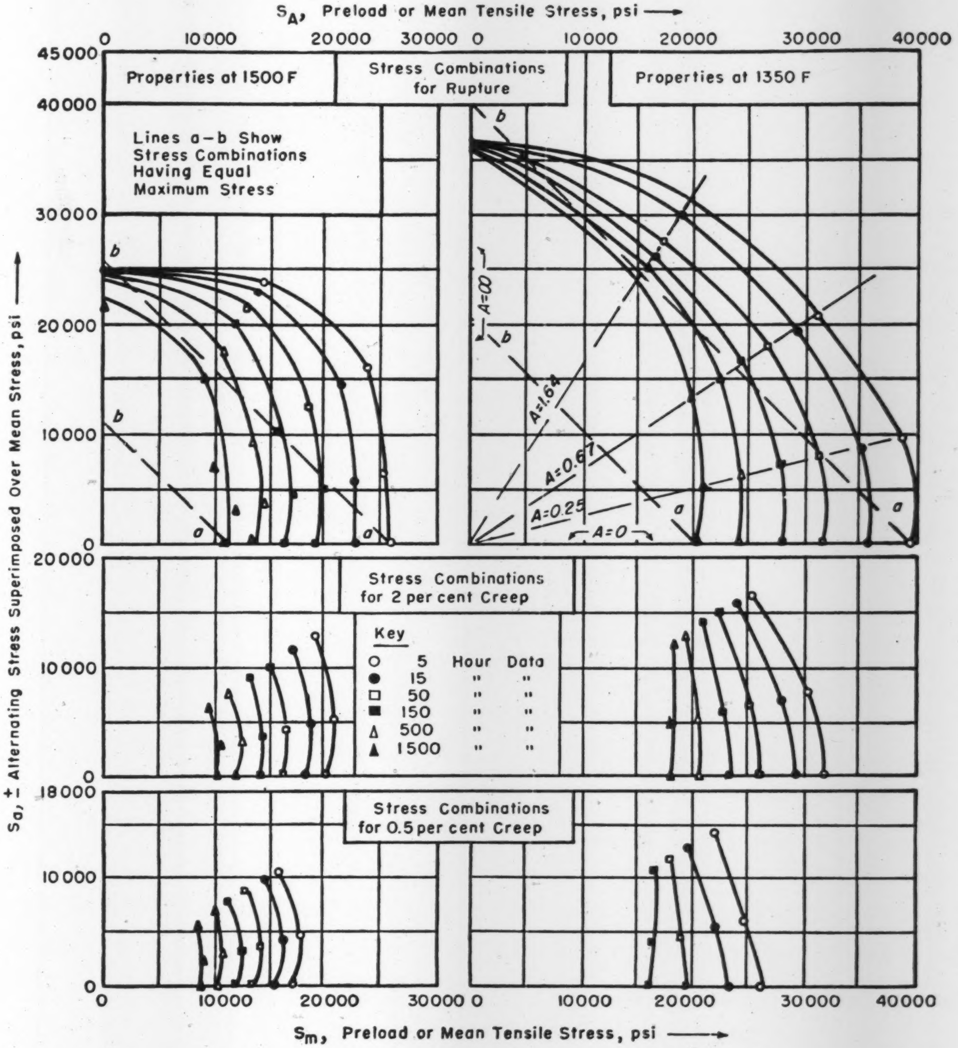


FIG. 7.—Static and Dynamic Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in Hours Indicated for N-155 at 1500 and 1350 F.

The number of stress cycles imposed during the dynamic test for each of these lives are 1.07, 3.22, 10.7, 32.2, 107, and 322 millions of cycles, respectively. As mentioned previously, dynamic creep data were procured over the stress ratio from $A = 0$ to 0.67, whereas rupture data were obtained over the range from $A = 0$ (horizontal line) to $A = \infty$ (vertical line).

Referring to the stress range diagrams

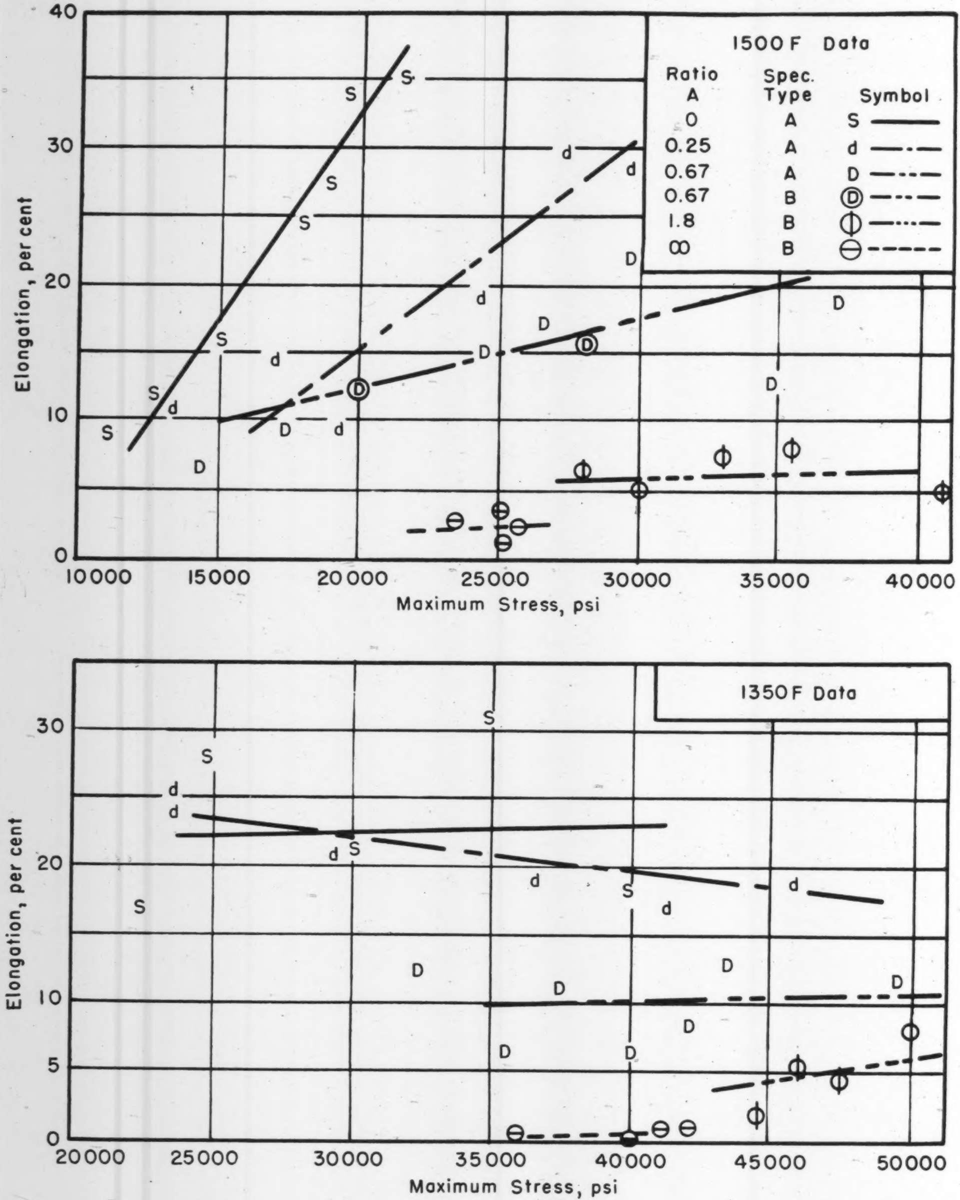


FIG. 8.—Effect of Dynamic Stress Ratio *A* and Stress Magnitude on per cent Elongation of Alloy N-155 at 1350 and 1500 F.

for rupture and creep of N-155 at 1350 and 1500 F the following observations may be made:

(*a*) In general, small amplitudes of alternating stress, say up to 35 per cent of the mean stress, do not greatly affect the life or creep associated with the same mean stress applied statically. In fact, the addition of small alternating force to a mean stress may even increase slightly the life at the corresponding mean stress. These observations are more apparent at long lives as compared to short lives and at 1500 F as compared to 1350 F.

(*b*) Since the distance between curves representing different hours of life indicates the effect of time (or number of stress cycles), the lower the stress ratio the greater the effect of time on strength. Therefore, creep and rupture are much more time-dependent than fatigue.

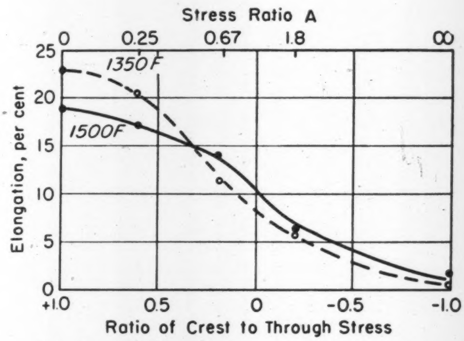


FIG. 9.—Effect of Dynamic Stress Ratio on Elongation at Failure in 150 hr for Alloy N-155 at 1350 and 1500 F.

(*c*) The ratio of reversed stress fatigue strength to static rupture strength is greater at 1500 F than at 1350 F, averaging approximately 1.4 compared to 1.26 for the range of lives investigated.

(*d*) The stress range diagrams for both rupture and creep fit a circular or Gerber's (6) relationship more closely than the straight line or modified Goodman relationship. Therefore design on the basis of the later two relationships will be on the conservative side.

A property frequently used by the designer to indicate the ductility of a material is the per cent elongation of the fractured specimen. Curves showing per cent elongation at 1350 and 1500 F as a function of mean stress and stress ratios from 0 to 0.67 for type A specimens and from 0.67 to ∞ for type B specimens are given in Fig. 8. Although there is considerable scatter in these data, in general the higher the stress ratio the smaller is the per cent elongation. At 1500 F the mean stress is also an important variable in determining per cent elongation; the lower the stress and the longer the life, the smaller is the per cent elongation. However, this stress magnitude effect decreases with increasing stress ratio; under static conditions ($A = 0$) the per cent elongation may increase more than three times with increasing stress level, whereas under partially reversed stress ($A = 1.64$) the per cent elongation is practically independent of stress level. At 1350 F, however, stress level is quite insignificant in determining per cent elongation; stress ratio is the most significant variable.

Figure 9 shows the effect of stress ratio on per cent elongation at failure. Since specimen life (or stress level) may be a variable under certain conditions, the two curves are based on a life of 150 hr. Of course, similar curves for other lives can also be drawn from the available data.

Under reversed stress conditions, one would expect insignificant elongation. The data show this to be reasonably true at 1350 F, but at 1500 F approximately 2.5 per cent elongation was measured. This may be due either to the difference in tension and compression creep properties or the inaccuracy of the gap subtraction method used to determine *corrected* elongation.

Although the elongation data diagrammed in Fig. 8 are "corrected" values, in that they exclude the largest surface gap at the fracture as explained previously they still include the effects of localized necking which preceeds fracture. In some respects the elongation data might be more significant if such localized necking effects could be excluded. This can be done by considering the elongation during the first two stages of creep only and excluding the third stage during which the localized necking effects occur. In order to procure elongation up to the third stage of creep, linear plots (not included in this paper) were made of creep *versus* time. An attempt was then made to determine the total creep during the first and second stages, up to the start of the third stage where the creep-time curves cease to be linear and where necking generally commences. However, the end of the second stage of creep and the beginning of the third or final stage is sometimes not well defined. Therefore, in order to fix this point more accurately the following approach was used. The second stage of creep was considered to end at the point where the minimum slope (second stage creep) line intersects a tangent to the third stage creep line at a point having 50 per cent greater slope than the second stage creep line.

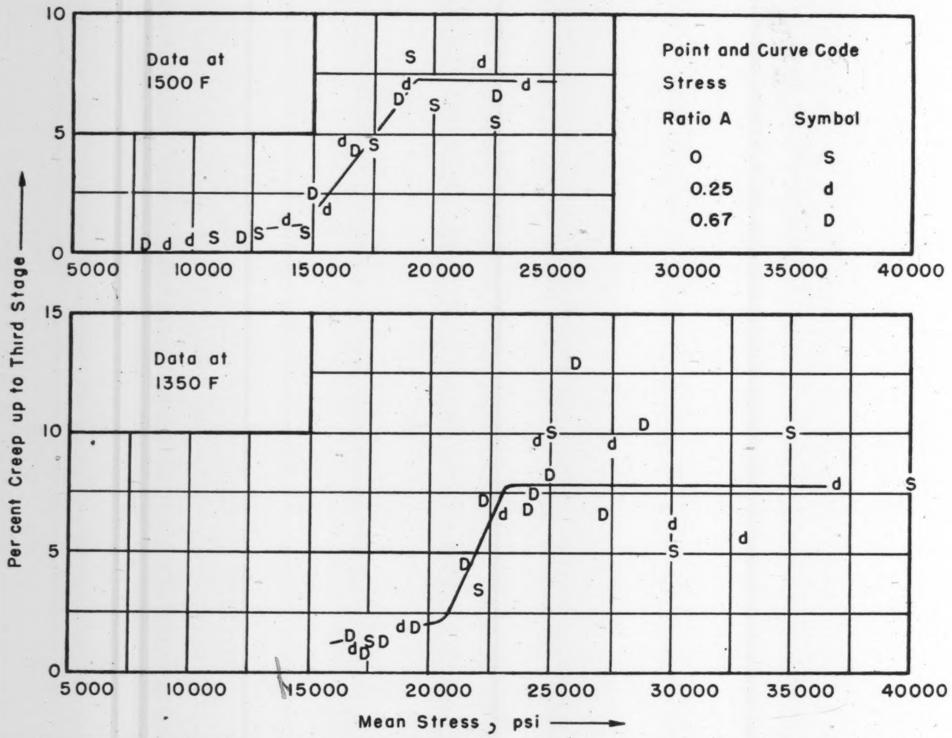


FIG. 10.—Effect of Dynamic Stress Ratio and Mean Stress on per cent Creep up to Third Stage on Type A Specimen N-155.

Although this approach is arbitrary, it does uniquely define a transition point. In cases having a distinct transition zone the beginning to the third stage of creep is not significantly different from that defined arbitrarily as indicated above.

The creep to the third stage, determined as explained above, is diagrammed in Fig. 10 as a function of mean stress ratio. Referring to this figure there appears to be three distinguishable zones:

(*a*) At low mean stresses there is relatively little elongation and scatter, and stress ratio effects are not distinguishable.

(*b*) At high stress levels considerably higher elongation occurs, and scatter increases pronouncedly without revealing any apparent stress ratio effects.

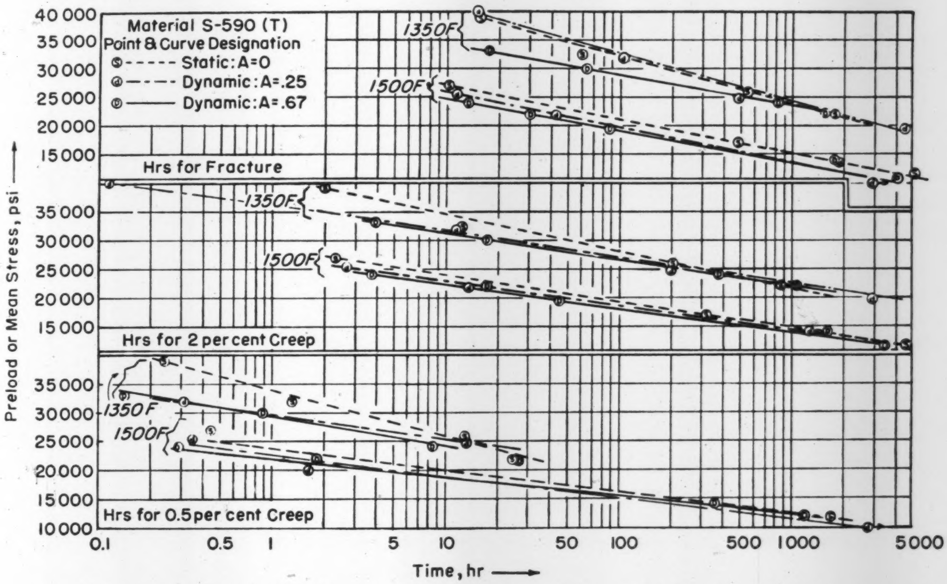


FIG. 11.—Time to Rupture, 0.5 per cent and 2 per cent Creep at 1350 and 1500 F Under Static and Dynamic Tensile Stress for S-590.

(*c*) The transition zone between these two regions displays a rather abrupt increase in elongation.

In none of the three zones is there any evidence of stress ratio effects similar to those displayed in the total elongation diagrams. It appears therefore, that the major effects of stress ratio on total elongation occur during the third stage of creep, at least for N-155 at stress ratios ranging from 0 to 0.67.

The data on creep to the third stage plotted in Fig. 10 shows similar patterns and order of magnitudes for both 1350 and 1500 F. The only significant difference apparent is the stress at which the transition zone discussed above occurs.

The significance of three zones observed in Fig. 10 is not yet clear. It has not been possible as yet to associate this elongation behavior with fracture characteristics (4). Other materials discussed below do not reveal such a pattern.

A discussion of whether or not the creep to the third stage is a better indication of the "true ductility" of a material than total per cent elongation after fracture is beyond the scope of this paper.

During the reversed stress fatigue testing of N-155 at 1350 F several interesting observations were made relating to the damping energy (5) in the material and the resultant rapid increase in specimen temperature immediately after the start of the alternating stress. At ±36,000 psi this increase was 25 F, at ±38,000 it was 120 F, and at ±40,000 psi it was 140 F, all these temperature increases generally occurring within a minute after starting the alternating load. No significant temperature increases were observable under like conditions at 1500 F. During 1000 F and room temperature tests, not reported in this paper, temperature increases at starting were as large as 400 and 1200 F, respectively.

These temperature increases of course affect testing techniques as related to presetting the furnace at a temperature lower than desired to allow for the increase caused by alternating force. However, more significant is the rough measure of damping energy provided by these temperature increases. Whether the damping at 1350 F is higher than at 1500 F, as indicated by the temperature increase observations is now being determined quantitatively by rotating beam tests (5).

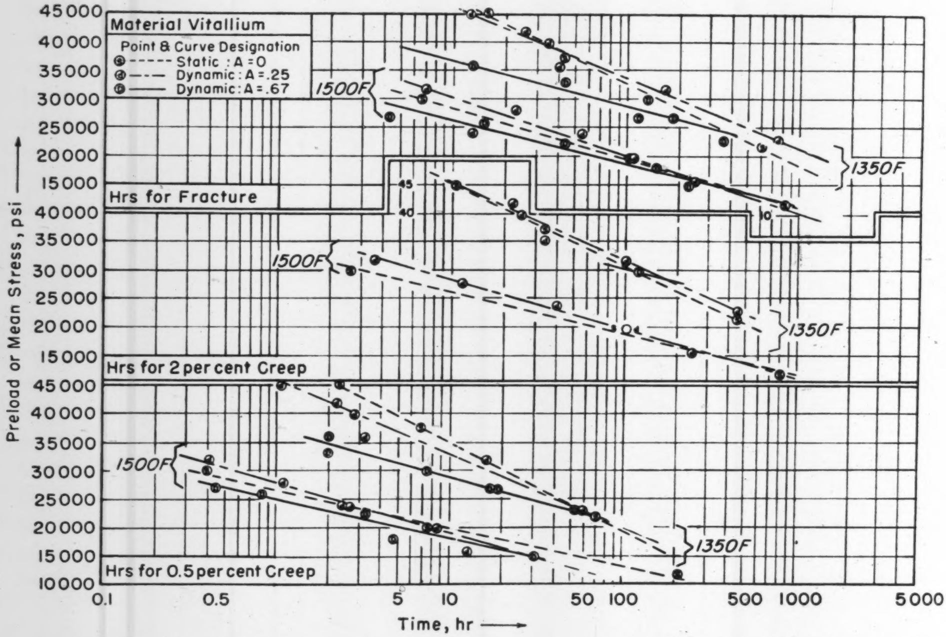


FIG. 12.—Time to Rupture, 0.5 per cent and 2 per cent Creep at 1350 and 1500 F Under Static and Dynamic Tensile Stress for Vitallium.

Dynamic creep and rupture data similar to that presented above for N-155 were also procured on S-590 and Vitallium at stress ratios *A* of 0, 0.25, and 0.67 and temperatures of 1350 and 1500 F. However, for brevity only the rupture and creep *versus* time diagrams (Figs. 11 and 12), the stress range diagrams (Figs. 13 and 14), and the ductility curves for S-590 only (Fig. 15) are presented. Although many of these data were published earlier (2) there are sufficient new data to justify inclusion of the extended curves for these materials in this paper. The stress range diagram for 2 per cent creep for Vitallium does not include the region at $A = 0.67$ since most of the Vitallium specimens failed before attaining this elongation (2).

The general patterns revealed in Fig. 7 for N-155 and discussed above are also apparent in the stress range diagrams of Figs. 13 and 14. No attempt is made in this paper to undertake a comparative evaluation of these materials since prop-

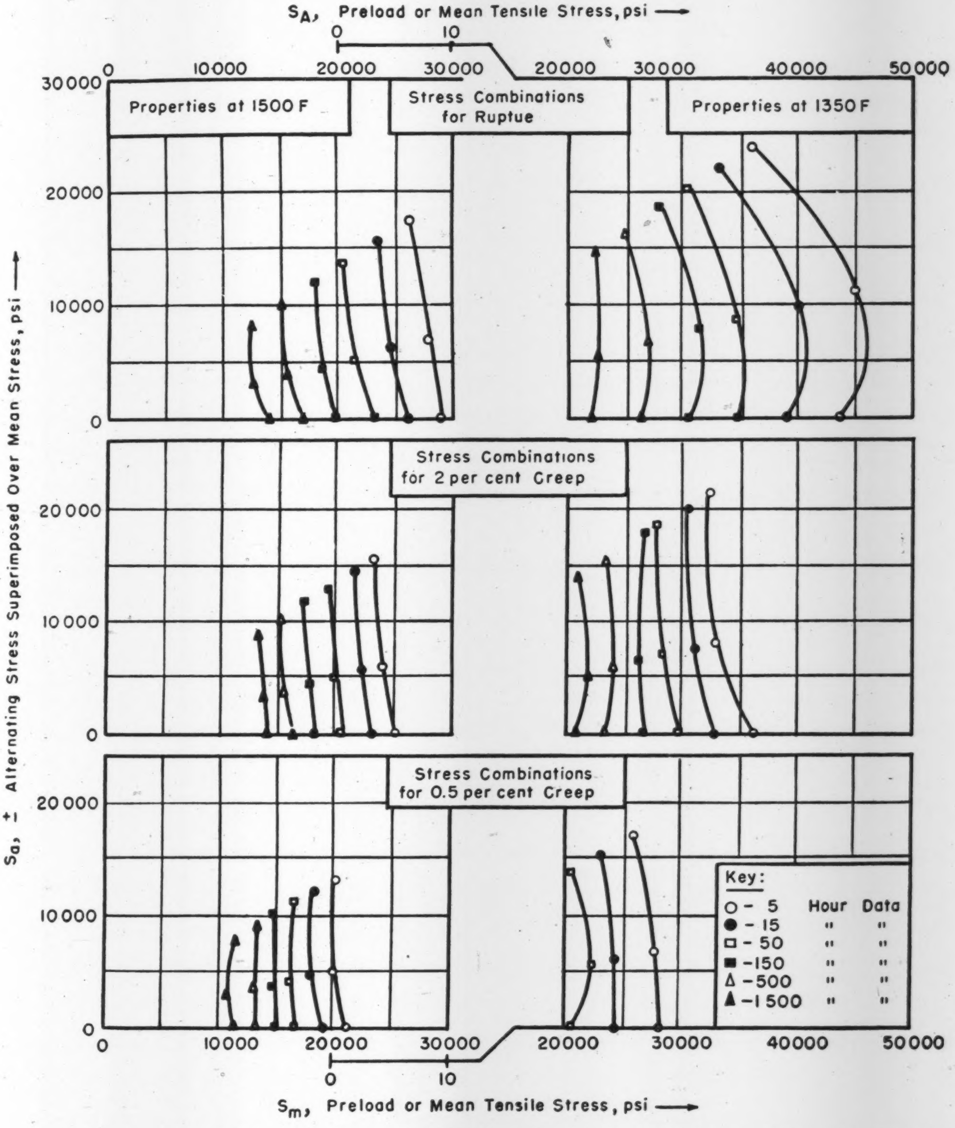


FIG. 13.—Static and Dynamic Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in Hours Indicated for S-590 at 1500 and 1350 F.

erties other than those considered here, such as corrosion resistance, thermal shock behavior, fabrication properties, etc., must be considered. However, it might be stated that Vitallium does display the best dynamic creep and rupture resistance at low stress ratios and for short lives. However, time at load affects Vitallium more pronouncedly than the other two materials (compare slopes of Figs. 6, 11, and 12, or compare distance between curves for different lives in Figs.

7, 13, and 14), so that this superiority does not hold up for long life.

N-155 in Figs. 8 and 10. The separation and change in slope according to stress ratio *A* is not nearly as distinct at 1500 F for S-590 as for N-155. Furthermore, the creep to third stage does not display a

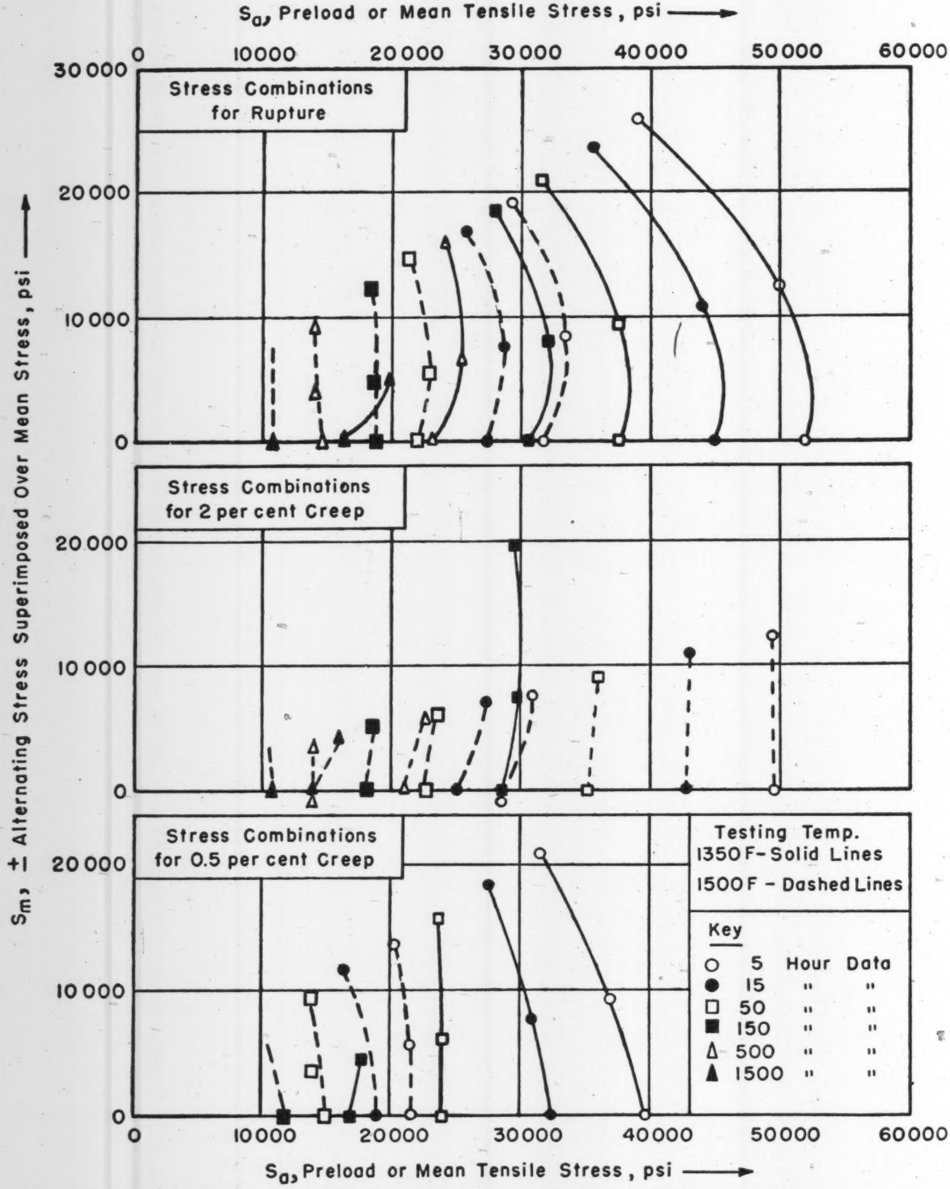


FIG. 14.—Static and Dynamic Stress Combinations which Cause Rupture, 2 per cent and 0.5 per cent Creep in Hours Indicated for Vitallium at 1350 and 1500 F.

The per cent elongation curves shown in Fig. 15 for S-590 are somewhat different in character from those shown for transition zone in S-590 as was observed in N-155. However, the N-155 pattern is partially followed in that the creep to third stage does fall approximately on the same line for all stress ratios and increases with increasing stress magnitude. Although the elongation diagrams for Vitallium are not included in this paper, the same general observations can be made; the separation of total elongation according to stress ratio is even less distinct and the creep to third stage is quite independent of stress magnitude and stress ratio in the range investigated.

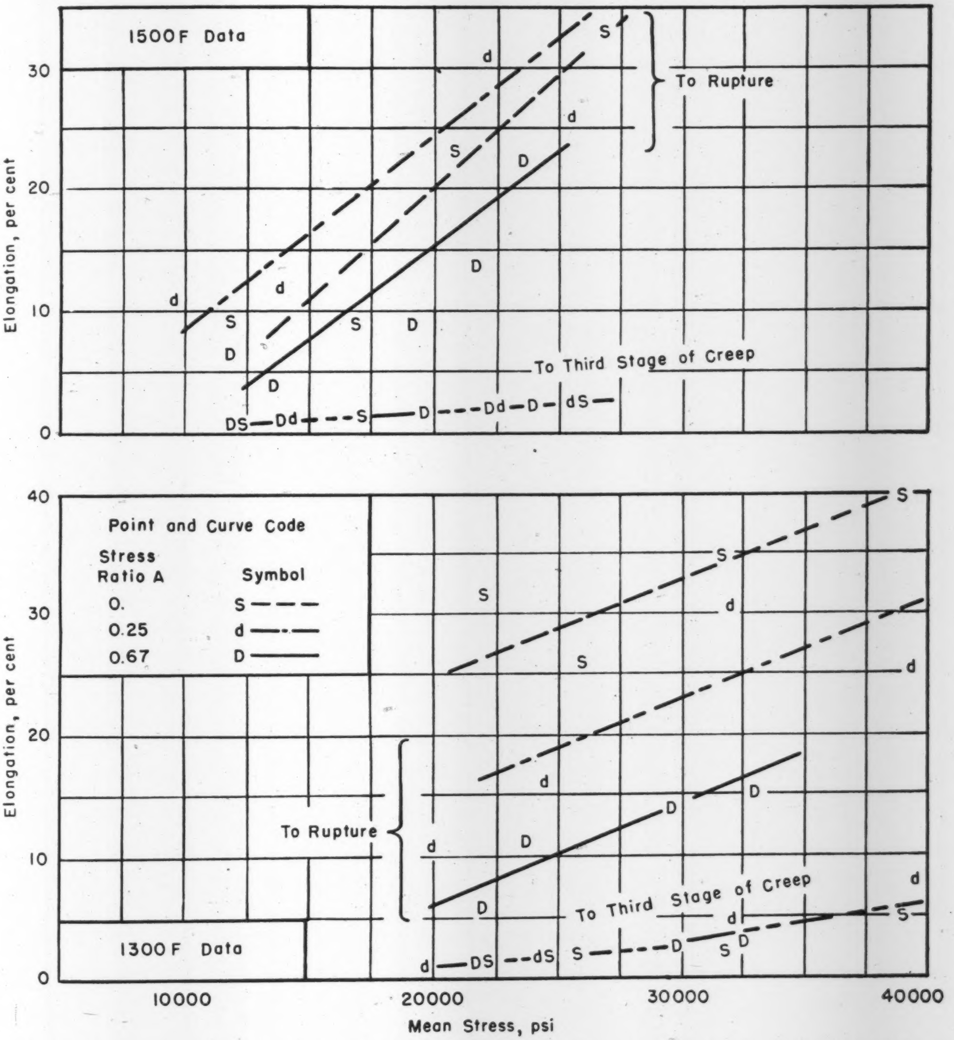


FIG. 15.—Effect of Dynamic Stress Ratio and Mean Stress on per cent Elongation at Failure of Type A Specimens S-590.

SUMMARY AND CONCLUSIONS

Fatigue, dynamic creep, rupture, and elongation data, procured with newly developed axial stress fixtures are presented for N-155, Vitallium and S-590 at 1350 and 1500 F.

The dynamic properties of N-155 were procured at alternating-to-mean stress ratios ranging from zero (static stress) to infinity (reversed stress fatigue) and the following observations were made:

(*a*) At high stress ratios (fatigue range) there is a relatively small decrease in strength with time or with number of cycles, whereas at low stress ratios (creep and stress rupture range) the strength is highly dependent on time. Thus, although the reversed stress fatigue strength is generally lower than the static rupture strength for relatively short lives, the opposite is generally true for long duration tests.

(*b*) In general small amplitudes of alternating stress, say up to 35 per cent of the mean stress, do not affect the life or creep associated with the same mean stress applied statically. In fact, the addition of small alternating stress to a mean stress may even increase slightly the life and decrease the creep at the corresponding mean stress. These observations are more apparent at long lives as compared to short lives and at 1500 F as compared to 1350 F.

(*c*) The stress range diagrams for both fatigue and stress rupture and also for creep fit a circular or Gerber's relationship more closely than the straight line or modified Goodman law.

Vitallium and S-590 alloy, investigated in the stress ratio range from 0 to 0.67 displayed general behavior patterns similar to those discussed above for N-155.

In general, the total elongation to fracture decreases with increasing stress ratios, being practically zero under reversed stress. Although there is considerable scatter in total elongation data, this elongation increases with mean stress in all cases except N-155 and Vitallium at 1350 F.

In order to eliminate the effects of localized necking during third stage creep and to procure what is perhaps a better measure of "true ductility," the elongation up to the third stage of creep was determined and diagrammed as a function of mean stress and stress ratio in the range from 0 to 0.67. In general there is less scatter in this type of elongation than in total elongation. Furthermore, stress ratio appears to have little influence and data for all stress ratios fall on the same curve. It appears, therefore, that the major effects of stress ratio on total elongation occur during the third stage of creep, at least in the range of stress ratios from 0 to 0.67.

Although the creep to the third stage increases gradually with stress magnitude for S-590 at 1350 and 1500 F and Vitallium at 1500 F, it is reasonably constant at all stress for Vitallium at 1350 F. In the case of N-155 at both 1350 and 1500 F, there is a uniform and gradual increase in creep to the third stage with increasing stress magnitude, followed by a transition zone of rapid increase, and finally at high stress the creep is relatively large but reasonably constant. The scatter in creep to the third stage is relatively small at low stress but relatively large at high stress.

Acknowledgment:

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Several of the authors' associates, particularly Messers. Robert Sell and John Sessler, were very helpful in the conduct of this work.

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DISCUSSION

MR. M. J. MANJOINE.[1]—Many of us have been waiting for additional results since Mr. Lazan presented his first paper in this field.

In the curves of mean stress as a function of the logarithm of time there is some speculation as to the extrapolation of the rupture curves for various stress ratios. It appears that all of these curves cross the static rupture curve for long times. This would mean that strength based on the mean stress for the dynamic loading is higher than the static rupture strength for long rupture times. Thus it seems that the effective stress to cause rupture for the dynamic loading is lower than the mean stress. This result was postulated in my paper.[2]

I would like to ask the authors, therefore, if they have any new data in this region where the dynamic and static curves cross.

MR. ALEXANDER YORGIADIS.[3]—Time sensitivity in completely reversed fatigue tests can only be determined if the fatigue tests are conducted at various frequencies.

In static (creep or creep-rupture) tests and in fatigue tests with a static preload over the alternating load, damage can be measured by the amount of creep, and this damage can be called "time sensitivity." However, since creep is negligible in completely reversed fatigue tests, there are no means to measure time sensitivity if the tests are conducted at one frequency, as was done by the authors. That is why I am wondering whether the authors' first conclusion is justified for the reversed stress condition.

MR. CYRIL E. PHILLIPS.[4]—I have two small points in which I think the authors will be interested. There have been carried out in the United Kingdom at least three separate series of high-temperature tests which have shown that, under axial fatigue stress and zero mean stress, creep of a test specimen can occur and it can be in either direction, that is, in tension or compression. I suggest that this uncertainty of direction of the creep which takes place could be a characteristic of the testing machine; it is not easy to ensure that the stress cycles are exactly equal on either side of the zero line.

A further point is that a few years ago, when we were interested in the high-temperature fatigue strength at high frequencies of certain turbine blade materials, we made determinations of one or two points on the mean stress—alternating stress curve of certain materials. This work showed that these curves extended well to the right of the final intersection with the horizontal axis (mean stress) and this hump, to which the authors have referred, was quite pronounced.

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[1] Westinghouse Electric Corp., East Pittsburgh, Pa.

[2] M. J. Manjoine, "Effect of Pulsating Loads on the Creep Characteristics of Aluminum Alloy 14S-T," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 788 (1949).

[3] Mechanical Engineer, Sonntag Scientific Corp., Greenwich, Conn.

[4] Mechanical Engineering Research Laboratory, East Glasgow, Scotland.

MR. YOH-HAN PAO.[5]—Mr. Lazan reported that under conditions of zero mean loads some tensile creep deformation was observed in the specimen. I think that this result is quite interesting and also to be expected. Because of the change in the cross-section of the specimen, zero mean load is not equivalent to a condition of zero mean stress. There is instead a mean tensile stress on the specimen and we should expect some tensile creep deformation to be developed.

I believe Mr. Lazan said that dynamic creep is not frequency sensitive and in support of his opinion he referred to results of a testing program carried out some time ago, simultaneously by several research laboratories, which showed that for the material tested dynamic creep is not frequency sensitive for testing speeds ranging from 1700 rpm to 7200 rmp. At Penn State we are also doing some work on the dynamic creep of plastic materials. Preliminary theoretical calculations have shown that the creep deformation of polymethyl methacrylate is not frequency sensitive above testing speeds of about 1800 rpm and short of shock conditions. This leads me to think that the creep deformation and creep rupture of a material, even though shown to be independent of testing speed for the range of 1700 rpm to 7200 rpm, may still be frequency sensitive below or above that range.

MR. B. J. LAZAN (*authors' closure*).—Mr. Manjoine inquires whether we have any additional data to indicate if the smaller slopes of the high-stress ratio curves in Fig. 6 and elsewhere persist beyond the intersection points. This would imply, as is pointed out, that for long rupture times the superposition of an alternating stress upon a mean stress would increase the time to rupture associated with the mean stress alone. Although this is not an impossible situation, the authors do not choose to extrapolate their data to the point where this would be indicated. Although the log-log plots of the data are reasonably straight for several cycles of time this does not, of course, preclude the possibility that a discontinuity does occur at lives longer than those investigated. Needless to say, the acquisition of data in the range beyond 5000 hr is extremely time consuming and the authors do not expect to undertake such long-term work in the near future.

Mr. Yorgiadis desires further clarification of the conclusion stated in the paper that "at high stress ratios (fatigue range) there is a relatively small decrease in strength with time or with number of cycles." This statement is made merely to indicate how flat the *S-N* fatigue curve can be at elevated temperatures. This does not imply, of course, that fatigue strength is frequency insensitive. However, tests made on N-155[6] in the range of frequencies from 1700 to 7200 cpm failed to indicate any frequency effects (although specimen shape and distribution factors may have exerted a camouflaging influence).

The presence of a "hump" to the right of static rupture point in the stress-range diagram, to which Mr. Phillips refers, has been observed for several materials.

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[5] Department of Engineering Mechanics, The Pennsylvania State College, State College, Pa.

[6] National Advisory Committee for Aeronautics Subcommittee on Heat-Resisting Materials, "Cooperative Investigation of Relationship Between Static and Fatigue Properties of Heat-Resistant Alloys at Elevated Temperatures," *NACA Report RM51A04*, March, 1951.

Although this hump appears to be a real one, data procured to date indicate it has rather negligible design significance.

Mr. Pao suggested the possibility that the change in cross-sectional area of the specimen during cyclic stress due to Poisson's ratio might account for the indication that tensile creep occurs under reversed stress. However, since Poisson's ratio would affect the cross-sectional area by only 0.1 per cent or so it is unlikely that this could account for a measurable affect. Due to impurities in the sine wave excitation and other machine calibration and accuracy factors, the actual tension-compressor force on the specimen probably deviates from the desired value by approximately two per cent, 20 times the Poisson's ratio affect. Thus it appears that factors other than the influence of Poisson's ratio in the cross-sectional area predominate.

In response to Mr. Pao's inquiry regarding the frequency sensitivity of dynamic creep, since there is no data on this effect no conclusions were drawn. However, if required to speculate I would agree with Mr. Pao that probably over a large frequency range dynamic creep would be found to be dependent on the testing frequency. The work referred to in the testing speed range from 1700 rpm to 7200 rpm was a fatigue testing program rather than a dynamic creep program as assumed by Mr. Pao.

The authors wish to thank the discussors for clarifying several aspects of this work.

DYNAMIC TESTING OF MATERIALS AND STRUCTURES WITH A NEW RESONANCE VIBRATION EXCITER AND CONTROLLER*

By B. J. Lazan,[1] J. Brown,[2] A. Gannett,[3] P. Kirmser,[3] and J. Klumpp[3]

Synopsis

The characteristics of near-resonance vibration are discussed to clarify the relationships among resonance amplification factor, damping energy, and dynamic modulus of elasticity. A newly developed machine is described for exciting and controlling resonance or near-resonance vibrations in materials and joints under various types of stress. This machine imposes an adjustable-while-running mechanical exciting force at a controllable frequency, and by means of automatic electronic controls maintains the desired vibration phase angle and the desired magnitude of the excited force This is done by controlling the frequency and magnitude of the exciting force, respectively. Equations are developed for determining the resonance amplification and other properties from the machine readings. The stability and accuracy of the machine are discussed. Data are presented on the damping and elasticity properties of aluminum and mild steel, and these are compared with results procured in rotating cantilever beam equipment. The resonance response, damping, and elasticity properties of a bolted joint were determined, and the effects of bolt tension and molybdenum disulfide lubrication are illustrated and partially analyzed.

One of the more frequent causes of service failure under dynamic forces is resonant vibration. The very serious amplification in vibrations caused by resonance, several hundred times in some cases, frequently results in dangerously large fatigue stress; and even if structural failure can be avoided, the resultant rough and noisy operation frequently necessitates correction.

In spite of the great importance of knowledge concerning the dynamic behavior of structures in the resonance region, relatively little experimental work has been done in the field. Initial work on this problem indicates that one of the main reasons for this inactivity is the inadequacy of existing testing and measuring equipment. Therefore, a necessary first step in a research program currently in progress at the University of Minnesota was the development of a new resonance vibration exciter and controller to impose sustained cyclic stress of controllable magnitude and to maintain the vibrations exactly at resonance or at some controlled near-resonance point. Such equipment was designed not only to study experimentally resonance and near-resonance phenomena in various types of linear and nonlinear systems, but also to permit undertaking studies of the damping capacity, dynamic modulus of elasticity, and other properties of materials and structures.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

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[2] Instructor, Syracuse University, N. Y.

[3] Project Engineer, University of Minnesota, Minneapolis, Minn.

One purpose of this paper is to describe the new mechanical equipment for exciting near-resonance vibrations and the electronic controls for maintaining the vibrating system in the desired state of resonance and at the desired alternating force. Test data procured with this equipment on both simple test specimens and a joint are also presented, not only to indicate stability, accuracy, and applicability of this machine, but also to reveal, in an exploratory way, some of the variables which affect the near-resonance response of materials and joints.

NATURE OF NEAR-RESONANT VIBRATION AND ITS RELATIONSHIP TO DAMPING AND ELASTICITY PROPERTIES

Figure 1 illustrates the well-known **(1)**[4] resonance curves for a linear, direct stress, single degree of freedom vibration system excited by a force of constant magnitude but variable frequency. This figure shows that an increase in frequency causes a gradual increase in amplitude of vibration, a peak being reached at the point of resonance where the frequency of the exciting force equals the natural frequency of the system. Beyond this resonance point the amplitude decreases with increasing frequency in the above resonance region. The amplitude A_1 or A_2 of vibration at resonance depends, among other things, on the damping energy that the vibrating system is capable of absorbing and dissipating; for large damping (curve 2) the resonance amplitude A_2 is relatively small, and for small damping (curve 1) a relatively large amplitude A_1 results. If A_0 is the amplitude of displacement caused by the exciting force F_0 applied statically (or at very low frequencies), then the ratios of A_2/A_0 and A_1/A_0 may be defined as the resonance amplification factor A_r. Since this factor is a reciprocal function of the damping capacity of the system, the ability of a vibrating system to absorb energy is of critical importance in defining the vibration amplitudes at or near resonance.

Systems with either nonviscous damping or nonlinear springs will generally display resonance curves different in form from that shown in Fig. 1; in many cases these curves are highly unsymmetrical **(1)**. However, it is still possible to specify an important characteristic of such curves in terms of resonance amplification factor as defined above.

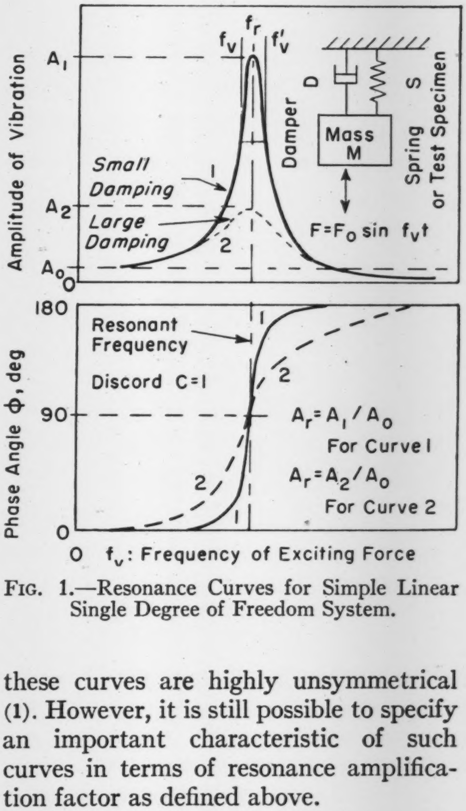

FIG. 1.—Resonance Curves for Simple Linear Single Degree of Freedom System.

The variation of vibration phase angle with frequency, which is utilized as a control function by the electronic controls discussed later, is also shown in Fig. 1. The phase angle ϕ is defined as the angle between the rotating vector representing the exciting force and the rotating vector representing the vibration displacement. At very low frequencies, well below resonance, the displacement follows very closely, or is in phase with, the exciting force; that is, the phase angle ϕ is zero. At resonance, this phase angle is 90 deg, the condition which permits the exciting force to feed maximum energy to the vibrating system. At high frequencies, well above resonance, the phase angle approaches 180 deg. Since the phase angle changes rapidly near resonance, it provides an extremely sensitive control for resonant vibrations.

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 875.

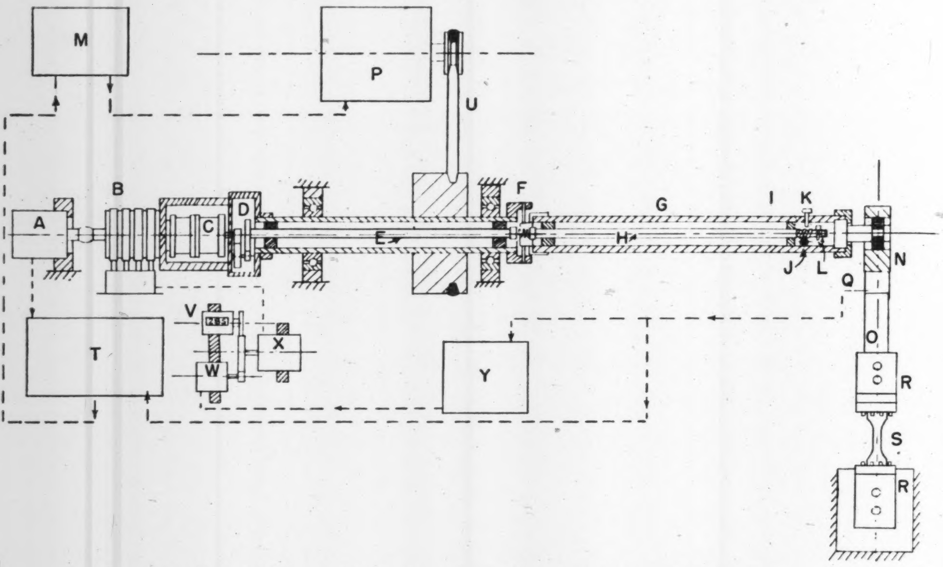

FIG. 2.—Schematic Diagram of Resonance Excitor and Controller.

A—A. C. Generator
B—Slip Rings
C—Selsyn Motor
D—Reduction Gears
E—Inner Shaft
F—Flexible Coupling
G—Outer Flexible Shaft
H—Inner Flexible Shaft
I—Worm Gear
J—Eccentric Screw
K—Balancing Screw of Outer Shaft
L—Balancing Screw of Inner Shaft
M—Motor Speed Control (Thymotrol)

N—Self Aligning Ball Bearing
O—Exciter Bar
P—Variable Speed Motor
Q—Accelerometer
R—Specimen Grip
S—Specimen
T—Phase Chassis
U—Pulley System
V—Counter Giving the Position of Screw *J*
W—Variable Direction Motor
X—Selsyn Generator Connected to *C*
Y—Force Chassis

In the actual machine described later, an actual test specimen is used in place of the spring and damper *D*, this test piece being either a simply shaped specimen or an actual joint or structural unit. Thus, the damping observed is due to the hysteresis loop in the test specimen or structure, and the spring constant of this specimen may be associated with either the dynamic modulus of elasticity of the material, for a simple test specimen, or with the over-all dynamic stiffness, for a test structure.

PREVIOUS MACHINES AND THEIR LIMITATIONS

In this work, a study was undertaken of both the resonance curve characteristics and the damping, elasticity, and fatigue properties of materials and structures. Existing machines for accurately studying resonance curve characteristics were found to be inadequate. Some mechanical oscillator-driven devices (2 to 6) have been tried for this purpose, but were found to be limited in utility or insufficiently stable for operation near resonance due to the inadequacy of controls. Electro-magnetic (7) and other electrical oscillators generally provide insufficient power input for testing structures (5, 8).

Existing equipment for measuring damping capacity and other dynamic properties are also inadequate (8). The static stresss-train hysteresis loop method is time consuming, requires instruments of extreme sensitivity, and is not readily adaptable to studies involving sustained cyclic stress because of the time required to impose the millions of stress cycles sometimes required. The dynamic stress hysteresis loop method (9) requires elaborate equipment of extreme accuracy and has been successfully used only on torsion specimens. Determination of damping from the heat developed during cyclic stress is quite inaccurate, even after elaborate heat transfer determinations are made, and it is also too sluggish, due to the heat capacity of the system, to reveal rapid fluctuations in damping capacity. The rate of vibration decay method (10), although relatively simple, is not adaptable to studies involving controlled cyclic stress; in fact, use of this method introduces variable stress conditions which may seriously affect the damping properties of the material. While the lateral deflection method (11, 12) is well suited for high stress tests it can be used only for tests under reversed bending stress on symmetrical specimens. The several resonant vibration methods of measuring damping (8), although requiring rather elaborate equipment, are well suited to sustained cyclic stress studies on both specimens and structures. Of these resonant vibration methods, the shape-of-the-resonance-curve method imposes a variable stress history on the specimen; the wattage-input-near-resonance method is usually quite inaccurate, especially for low damping materials; and the energy-input-by-an-oscillator method (4) was still not completely developed.

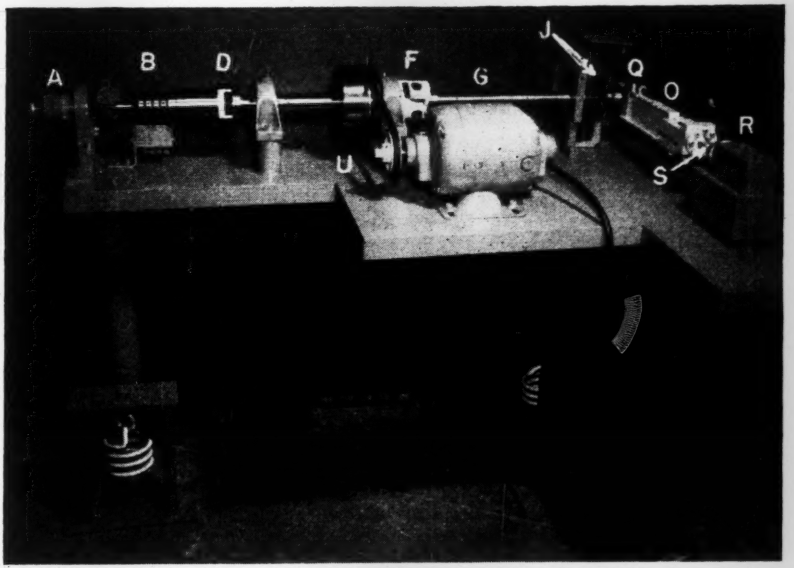

FIG. 3.—Photograph of the Mechanical Vibration Excitor.

DESCRIPTION OF THE NEW RESONANCE VIBRATION EXCITOR AND CONTROLLER

In view of the limitations in existing equipment, a new oscillator-driven resonance machine utilizing the energy-input-by-an-oscillator method for studying materials and structures at resonance was developed. Electronic controls to assure stable operation at practically any near-resonance point were also developed to increase the utility of the machine. This machine is designed to excite near-resonant vibrations of controllable amplitude at a controllable phase angle. Thus, complete resonance response curves may be accurately determined. It is further possible to procure data on the damping properties by maintaining the vibrating system exactly at resonance, at which point the ratio of the force exciting the vibration to the force induced in the specimen or structure is a function of damping energy. Furthermore, the dynamic modulus of elasticity may be calculated from the frequency of resonant vibration, the effective mass of the vibrating system, and other known factors.

The principle of operation of this machine may be understood from the schematic diagram of Fig. 2 and the photograph of Fig. 3. These particular figures show the machine setup for resonance studies of beams. The specimen or structure *S* is subjected to forced resonant vibrations excited by the centrifugal force produced by the revolving eccentric *J*. Variable speed motor *P* drives shaft *G* through pulley system *U* and universal joint *F*, causing the centrifugal force produced by eccentric *J* to be transmitted through bearing *N* to the test structure *S*. The speed of motor *P* can be adjusted to produce a resonant vibration of the desired type in a system in which the test specimen or structure is the spring and damper elements. The specimen is free to vibrate without significant restraint by the exciting equipment because of the freedom of motion allowed by universal joint *F* and flex-plate support used in the mount for bearing *N*. In order to control the force in the test specimen, the radial position or unbalance of eccentric *J* may be adjusted by selsyn *C* attached to the outer shaft *G*, which is supported by two pillow blocks. This adjustment may be accomplished during rotation of drive shaft *G* since the stator of the selsyn *C* is fixed to the drive shaft and fed by brush-slip ring assembly *B*. To adjust the eccentricity the selsyn operates through gear reduction *D*, shaft *E*, the universal joint within *F*, and worm *I*, which meshes with worm gear teeth cut in threaded eccentric *J*. Thus, as worm gear *I* is turned by selsyn *C*, the threaded eccentric *J* is rotated and therefore moves radially. This radial positioning of the eccentric *J* either decreases or increases the exciting forces as desired.

Vibrations may be excited either at or near resonance. Proximity to resonance is determined from the phase angle between the vector representing the alternating displacement and the vector representing the alternating force. This vibration phase angle is determined from the phase relationship of two voltage outputs. One output is from the accelerometer *Q*, which vibrates with the specimen and produces a voltage output proportional to and in phase with the acceleration, 180 deg out of phase with respect to the displacement. The second voltage is from a small alternating current generator *A*, attached to the free end of shaft assembly, which produces a sinusoidal voltage output in phase, or bearing any desired phase relationship, with the alternating force caused by eccentric *J*. This voltage gives the orientation of eccentric *J* and therefore the time relationship of the exciting force. The phase angle between the accelerometer voltage and generator voltage is maintained at 90 deg for resonant vibrations.

The magnitude of the exciting force produced by the eccentric may be determined from the position of the eccentric and the frequency, both of which are indicated in the control panel. The resonance amplification factor, a reciprocal function of damping capacity, may then be calculated (4) from the ratio of the force in the specimen, determined from the accelerometer output, to the force which excites the resonance vibration. The dynamic stiffness of the specimen may be determined from the frequency at resonance, the effective mass of the system, and other known factors.

Although the basic exciting, measuring, and controlling system described was for beam tests, it can be used to impose many different types of stress by utilizing different setups. Since the behavior of the entire vibrating system affects the measurements, it is necessary to keep energy losses, flexibility, lost motions, etc., in supporting frames and joints very small if true specimen behavior is to be measured. Additional details on the mechanical features of this machine are given in reference (13).

As indicated previously, electronic controls were developed to maintain stable vibration of controllable magnitude at any desired phase angle. Thus, there are actually two control functions, one for maintaining the desired amplitude and the second for phase angle control. The accomplishment of these control functions requires the utilization, as indicated below, of the two voltage outputs discussed previously.

The excited force in the test specimen is held at a preset value by maintaining the accelerometer output at a constant value. This is done by rectifying the accelerometer voltage, comparing it to a preset voltage, and utilizing the amplified difference to control the direction of rotation of a motor which changes the magnitude of the exciting force. This in turn changes the magnitude of the excited force and the resultant accelerometer voltage until it matches the voltage preset with a helipot in the force controller.

The frequency of the exciting force is controlled by the phase discriminator circuit which maintains the vibrating system at or near resonance. This is done by maintaining the phase angle between the voltage from the accelerometer and the voltage from the a-c generator in a fixed relationship, at 90 deg for resonance. A phase discriminator receives both voltages, interprets them, and accomplishes this control by either increasing or decreasing the speed of the driving motor, and correspondingly changing the frequency of the exciting force, so as to maintain the vibrating system at the desired phase angle. Electronic circuits and other details of this machine are given in an earlier paper (13).

EQUATIONS IN REDUCING AND INTERPRETING RESONANCE MACHINE DATA

The calibration of the resonance machine, the reduction of data procured in this machine, and the correlation of such damping data with those procured in other types of tests requires the use of several equations, some of which are derived or listed below.

The exact equations for defining the shape of the resonance amplitude and phase angle curves for the system damped by material hysteresis have not yet been developed. Different materials may display damping which is nonlinear in various ways, and in fact even the same materials may display different types of nonlinearity at various stress levels and stress history.[5] It is therefore improbable that one set of equations will cover all hysteresis-damped systems.

Similarly, there are many important aspects of structural damping which have not been analysed. Although the equations which define the behavior of certain types of structurally damped systems, such as those involving Coulomb damping (15), have been developed, the implications of important deviations from the simplifying assumptions used in the theory are not known.

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[5] For example, the damping of mild steel (**14**) is insensitive to frequency and stress history up to a certain stress level, beyond which it is sensitive to both. At stresses near the fatigue limit, for example, the damping may first increase and then decrease with increasing frequency.

However, it is still possible to handle these types of systems, even in the absence of their exact equations. As long as the resonance amplification factor is reasonably large, then even though the damping may be quite nonlinear the system may still vibrate sinusoidally, within practical limits, and be considered linear for purposes of resonance amplification and perhaps other resonance response considerations. Therefore, the relationships derived in this paper for the viscous damped system will be applied in a later section to nonlinear systems, and as long as the resonance amplification factor is reasonably large,[6] the accuracy in many cases may be sufficient for engineering purposes.

The following equations indicate the relationship between A_r and the shape of the amplitude and phase curves near resonance. These equations are used in the analysis of experimental data presented in sections which follow.

The amplitude curve near resonance shall be considered first. From the equations which define the viscous damped system (1) it can be shown that:

$$A_v = \left[(1 - C^2)^2 + \left(\frac{C}{A_r}\right)^2\right]^{-\frac{1}{2}} \quad \ldots\ldots (1)$$

See Appendix for definition of terms and symbols.

Solving the above equation for the resonance amplification factor:

$$A_r = \frac{\left[\left(\frac{A_r}{A_v}\right)^2 - C^2\right]^{\frac{1}{2}}}{1 - C^2} \quad \ldots\ldots (2)$$

Since these equations are to be used near resonance, discord C will generally fall well within the range from 0.9 to 1.1, usually from 0.96 to 1.04. Therefore, the denominator $(1 - C^2)$ in Eq 2 may be replaced, without significant error, by $2(1 - C)$. Thus:

$$A_r = \frac{\left[\left(\frac{A_r}{A_v}\right)^2 - C^2\right]^{\frac{1}{2}}}{2(1 - C)} \quad \ldots\ldots (3)$$

Equation 3 suggests the following method of determining A_r from the shape of the resonance curve.

1. To determine the denominator $2(1 - C)$, measure the width $(f'_v - f_v)$ of the resonance curve (see Fig. 1) at any point and divide by f_r. Since at resonably large values of A_r the resonance curve is resonably symmetrical:

$$\frac{f'_v - f_v}{f_r} = \frac{2(f_r - f_v)}{f_r} = 2(1 - C)$$

Even where serious nonsymmetry exists the above equation may provide a reasonably accurate average value.

2. Determine A_v (or $k\ A_v$, where k is any constant) at the width measuring location. Also determine A_r (or kA_r, where k is the same constant used above), and the ratio $kA_r/kA_v = A_r./A_v$:

If the width of the resonance curve is measured at the location where $A_v = 0.707\ A_r$, then $[(A_r/A_v)^2 - C^2]^{\frac{1}{2}} = 1$ for reasonably large A_r, and Eq 3 becomes:

$$A_r = \left[\frac{1}{2(1 - C)}\right]_{A_v = .707A_r} \quad \ldots (4)$$

This provides a convenient method of determining A_r.

Considering now the phase angle relationship near resonance, it can be shown from the equation for the viscous damped system (1) that:

$$\cot \phi = A_r \frac{1 - C^2}{C} \quad \ldots\ldots\ldots (5)$$

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[6] Insufficient work has been done to date to define the term "reasonably large." However, the data presented in the next sections may help clarify this term.

Therefore, slope of cot ϕ *versus* C curve at any discord C is given by:

$$\frac{d(\cot \phi)}{dC} = -A_r\left(\frac{C^2+1}{C^2}\right) \ldots\ldots (6)$$

$$A_r = -\frac{1}{2}\left[\frac{d(\cot \phi)}{dC}\right]_{\text{at } C = 1} \ldots (7)$$

Thus, A_r equals half the slope of the cot ϕ *versus* C plot at resonance where $C = 1$.

The following equations are derived to enable the correlation of the A_r data procured in the resonance machine with the damping and elasticity data procured in the rotating beam machine (2, 14). It is shown (16) that if damping energy can be expressed by the equation:

$$D = JS^n \ldots\ldots\ldots\ldots\ldots (8)$$

then

$$\frac{D}{D_a} = \frac{n+2}{2}\left[\frac{1-\left(\frac{r}{R}\right)^2}{1-\left(\frac{r}{R}\right)^{n+2}}\right] \ldots\ldots (9)$$

See Appendix for definitions of symbols and terms.

Since elastic energy W is proportional to S^2, $n = 2$ may be substituted in Eq 9. The result is:

$$\frac{W}{W_a} = 2\left[\frac{1-\left(\frac{r}{R}\right)^2}{1-\left(\frac{r}{R}\right)^4}\right] \ldots\ldots\ldots (10)$$

It is also shown in Appendix A of Spath's paper (2) that the energies associated with the rotating-beam test may be expressed as follows:

$$D_a = \frac{D_0}{U} = \frac{\pi W \sin \theta\, kH}{U} \ldots\ldots (11)$$

and

$$W_a = \frac{W_0}{U} = \frac{W \sin \theta\, kV}{2U} \ldots\ldots (12)$$

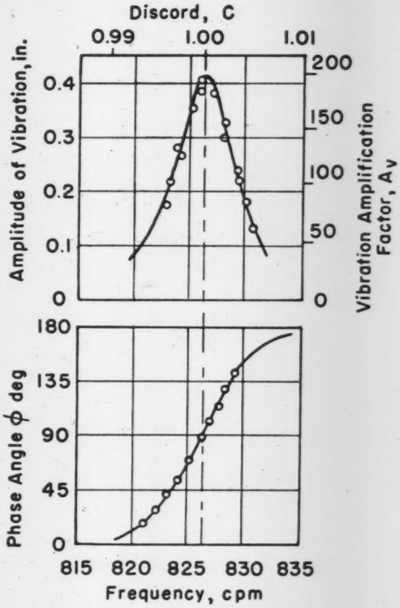

FIG. 4.—Resonance Curves for Solid Cylindrical Aluminum Specimen Under Bending Vibration.

Therefore

$$A_r^d = 2\pi\frac{W}{D} =$$

$$\frac{4\pi\left[\frac{1-\left(\frac{r}{R}\right)^2}{1-\left(\frac{r}{R}\right)^4}\right] W \sin \theta\, kV\left(\frac{1}{2U}\right)}{\frac{n+2}{2}\left[\frac{1-\left(\frac{r}{R}\right)^2}{1-\left(\frac{r}{R}\right)^{n+2}}\right] 2\pi W \sin \theta\, kH\left(\frac{1}{2U}\right)}$$

$$A_r^d = K_m = \frac{4}{n+2}\left[\frac{1-\left(\frac{r}{R}\right)^{n+2}}{1-\left(\frac{r}{R}\right)^4}\right]\frac{V}{H} \ldots (13)$$

For additional relationships between A_r, D, and other properties see earlier paper by one of the authors (4).

TEST DATA ON MATERIALS AND COMPARISON WITH ROTATING BEAM DATA

In order to procure an indication of the stability of the resonance machine and its control system a series of tests were performed on solid aluminum specimens using the bending setup shown in Fig. 2. During these preliminary tests the resonance curve characteristics were explored, Fig. 4 being an example of one such resonance curve.

This, as well as other resonance curves discussed later, was procured by rotating the stator of the tachometer generator (see part A in Figs. 2 and 3) to the desired phase angle and, with the machine operating on automatic controls, reading the corresponding values of accelerometer output, amplitude of vibration, and frequency. The vibration amplitude and phase angle can then be plotted as a function of frequency as shown. Since 24S-T aluminum has rather small damping energy, its resonance amplification factor is rather large ($A_r \simeq 200$ for test diagramed in Fig. 4) and its resonance amplitude and phase angle curves are consequently sharply peaked. All the experimental points shown in this figure lie within a frequency band having a width of 1 per cent. A change of only 0.1 per cent in the exciting frequency, say from 822 rpm to 822.8 rpm, will change the amplitude of vibration approximately 35 per cent and the phase angle over 10 deg. Thus, this test on aluminum is a critical indication of machine stability. Even for this sharply peaked curve the performance proved to be satisfactory. In highly damped systems, having rather flat resonance curves, the stability requirements are, of course, less demanding. From Fig. 4 it is apparent that extremely sensitive frequency measurement is necessary for defining the resonance curves for low damping cases. The frequency measuring device used had a probable accuracy of approximately $\frac{1}{2}$ rpm. This is insufficient for an accurate determination of the limitations in applying the equations derived previously for viscous damping to the hysteresis damped vibration. Nevertheless, the A_r values for the solid aluminum specimen tested as diagrammed in Fig. 4 were determined by the several methods discussed previously with the following results:

Using Eq 3, with $\frac{A_r}{A_v} = 1.41$, $A_r = 206$.

Using Eq 3, with $\frac{A_r}{A_v} = 2.32$, $A_r = 246$.

Using Eq 6, and slope of cot ϕ *versus* C curve, $A_r = 170$.

Using rotating beam damping tests and K_m, K_e and K_s ((16) and Appe ndix), $A_r = 220$.

Considering the likelihood of frequency measurement errors, as discussed above, and also considering the many factors, such as stress history, rest, etc., which affect the damping energy of a material (12, 14), the check among the several methods of determining A_r is considered adequate.

As a further indication of the stability and accuracy of the resonance machine during long periods of operation and its utility in providing significant A_r data, a series of damping, elasticity, and fatigue tests were undertaken on mild steel. These tests were also intended to confirm the general damping behavior under sustained reversed stress previously observed for mild steel (12) and also to check quantitatively the results of the resonance machine against previously determined rotating beam data.

In these mild steel tests a series of rectangular specimens (1.5 in. wide by 0.38 in. deep by approximately 2 in. length of test section) were vibrated exactly at resonance (phase angle ϕ maintained at 90 deg). Each specimen was subjected to a different reversed stress which was maintained constant during the sustained vibrations until fatigue failure occurred. The type of data procured during this fatigue test is diagrammed in Fig. 5, which shows the changes which occur as a function of abscissa N, the number of cycles of stress. The quantities recorded during this sustained vibration test were (*a*) the tachometer output, which indicates the resonant frequency, and (*b*) the reading of the counter, which indicates the unbalance of the exciting eccentric. The magnitude of force exciting the vibration may be determined from the product of the eccentric counter reading and the square of resonant frequency. The ratio of this force to the excited force, easily determined from the stress or amplitude of vibration, is the resonance amplification factor A_r shown in this diagram. The very pronounced decrease in A_r shown in this figure in agreement with the rapid increase in damping energy for the same material as discussed in Reference (12). The change in dynamic modulus of elasticity (12) of the material may be quantitatively determined from the decrease in resonant frequency or the increase in amplitude of vibration shown in Fig. 5. Here, again the results of the resonance tests are in agreement with those of the rotating beam, but elaboration on this is beyond the scope of this paper.

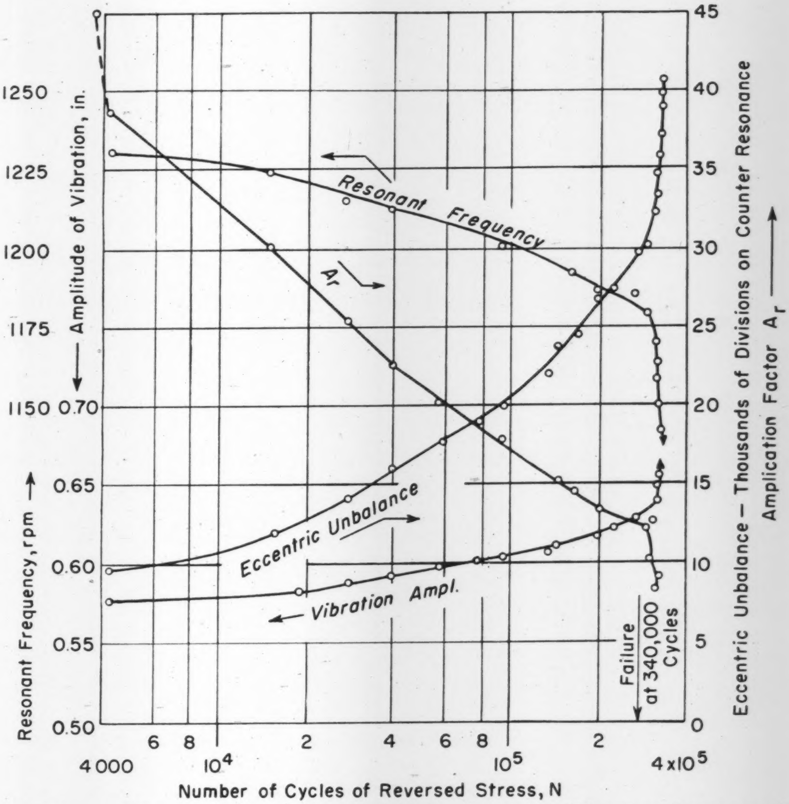

FIG. 5.—Effect of Reversed Cyclic Stress Maintained at ±44,300 psi on Resonance Response of a Mild Steel Beam.

A quantitative comparison of the damping energy at several stress magnitudes as determined in the rotating-beam equipment with the A_r values determined with the resonance machine is shown in Fig. 6. The material factor K_m shown in this diagram, which corresponds to the resonance amplification factor A_r^d under direct uniform stress, is discussed in detail in Reference (16) (see also Appendix). The virgin material, or more accurately the material with a stress history of only 10 cycles, has K_m values shown by the uppermost curve. However, K_m is reduced considerably by sustained cyclic stress and attains the values shown by the lowest curve prior to fatigue failure. It is now possible to compute the resonance amplification factor from the relationship $A_r = K_m \cdot K_c \cdot K_c$ discussed in Reference (16) (see also Appendix). For the mild steel used the damping exponent n varies between 16 and 27 for the range of stress magnitudes and stress histories

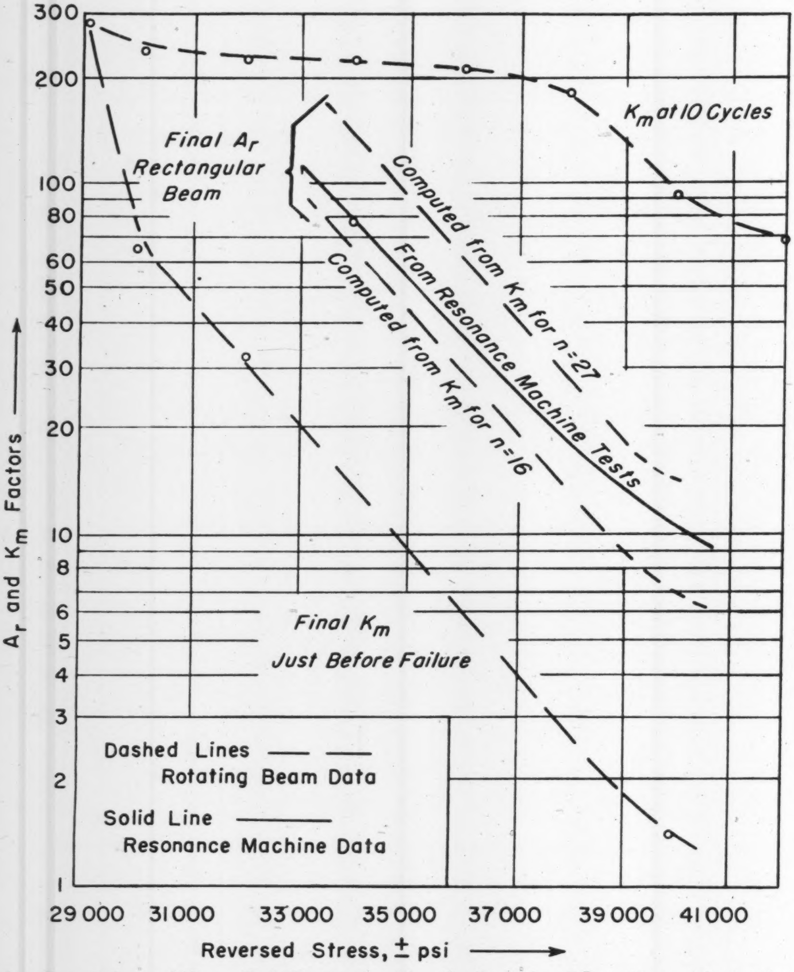

FIG. 6.—Comparison of K_m and A_r Determined by the Rotating Beam Test with A_r Determined by the Resonance Test, All Data on Mild Steel.

covered by Fig. 6. Under these conditions

K_c varies between 4.8 (at $n = 16$) and 10 (at $n = 27$), and

$K_s = 1$ for uniformly stressed beam.

Using the factors indicated above, A_r values for a rectangular beam, computed from the rotating beam damping energy data, are shown by the dashed lines in Fig. 6. The values of A_r as determined directly from the resonance tests are shown by the solid line. Considering the many variables which affect the damping behavior of materials and the approximation (16) which must sometimes be made in their mathematical analysis, this check shown is considered good.

A similar check between resonance and rotating beam data was not attempted on the virgin material because the few minutes or so required to adjust and stabilize the resonance machine does not permit procuring reliable A_r at less than a few thousand stress cycles.

Additional data indicating the reliability and accuracy of the resonance machine when used on a material with damping exponent n as high as 13 are given in Reference (16).

RESONANCE TESTING OF JOINTS

A series of resonance tests were undertaken on a bolted lap joint in order to study the general behavior of the resonance machine when used on a nonlinear system. Also some of the variables which affect the A_r values for the joint were briefly explored.

The joint used and its method of loading is shown in Figs. 7 and 8. The bolts fit freely within oversize holes in the mild steel plates so as to avoid indeterminateness, that is, to assure that no shearing force is developed in the bolts and that the joint is held together entirely by friction. The tension in the connecting bolts and the consequential friction producing normal pressure in the joint plates was adjusted to and maintained at the desired value through use of calibrated springs S. The friction surfaces which absorbs the damping energy are 1–2 and 3–4. The purpose of springs M was to keep the joint assembly centered so as to avoid drift at the friction surfaces and the resultant shear contact between plates and bolts.

The resonance response characteristics

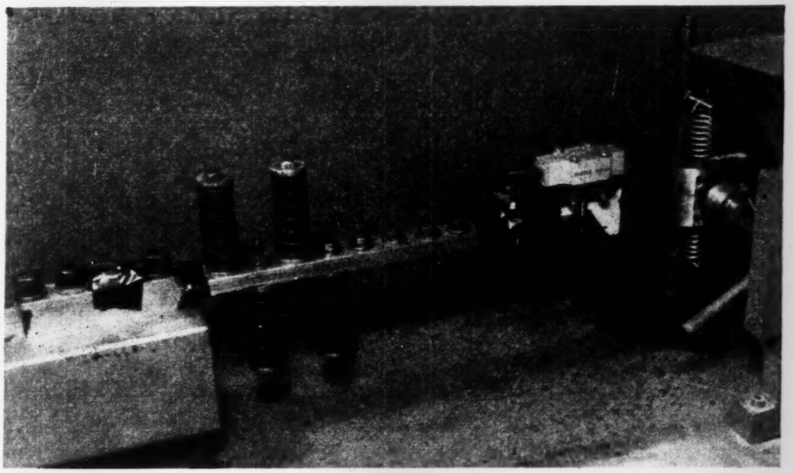

FIG. 7.—Photograph of Joint in Machine.

of this joint were explored as a function of two variables; the bolt pressure and the effect of adding molybdenum disulfide powder at the friction surfaces. This second variable was briefly studied since recent work (17) indicates that molybdenum disulfide (MoS_2) can be an effective surface lubricant and increase damping.

Figure 9 shows the resonance curves for the joint without MoS_2 at the various bolt pressures indicated. All curves are plotted as a function of frequency f_v of the exciting force; the uppermost series of curves indicating the amplitude of vibration, the middle curves the phase angle ϕ, and the lowest series of curves was included so that A_r could be computed readily from Eq 7 and also to indicate roughly the degree of nonlinearity existing in this type of joint damping as discussed below.

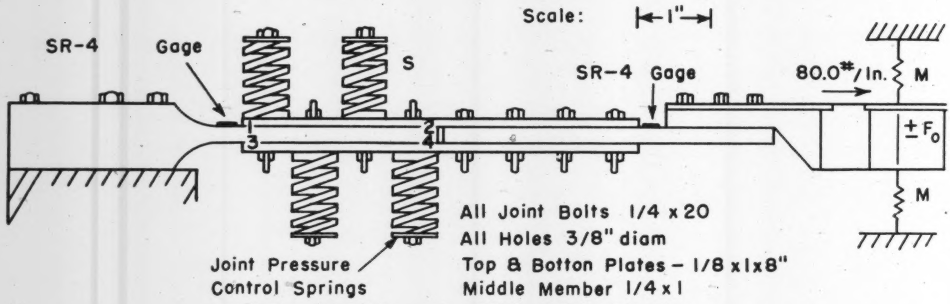

FIG. 8.—Schematic of Bolted Joint Test Setup.

As explained previously the general equations which define the resonance response characteristics of hysteresis damped and joint damped vibrations have not yet been developed. Consequently, it is desirable to investigate partially the degree and implication of the nonlinearity present in the curves shown in Fig. 9 with reference to the standard equations (12) and those derived in a previous section for the viscously damped vibrations.

First looking at the amplitude curves, a high degree of nonsymmetry is present which may be considered to be an indication of the nonlinearity present. The higher the damping, or the smaller the resonance amplification factor, the greater the nonsymmetry apparent; for example, compare the curves for 100 and 200 lb bolt pressure, where the damping is relatively high, with the dashed curve for 1200 lb bolt pressure where damping is relatively low. Similarly, the phase angle curves display nonsymmetry which is indicative of the nonlinearity present. However, the most critical indication of nonlinearity is perhaps the cotangent ϕ curve. Referring to Eq 6, previously derived, for the linear viscous damped system the slope of the cot ϕ *versus* f_v curves should be reasonably constant, that is, the curves should be straight lines, as long as discord C is reasonably close to 1. The greatest deviation of the C values in Fig. 9 for the range of cotangent ϕ plotted is less than 0.04, for which range the variation in the slope of the cot ϕ *versus* C curve should be less than 4 per cent. Thus, for all practical purposes the curves may be considered to be straight lines. The considerable deviation of the actual curves shown in Fig. 9 from straight lines is of course an indication of the degree of nonlinearity.

The A_r and resonant frequency values determinable from Fig. 9 are summarized in Fig. 10 as a function of bolt pressure.

Also included in this figure are data for the joint lubricated with molybdenum disulfide.

The resonance amplification factors for the joint without MoS_2 were computed by three different methods: (*a*) from the ratio F_s/F_0, as determined from readings provided by the resonance machine operated exactly at resonance ($\phi = 90$ deg), (*b*) from Eq 3 based on the width of the resonance curve method, and (*c*) from Eq 5 based on the slope of the cotangent ϕ method. For the linear, viscous damped vibration, all three A_r curves should coincide, since the assumptions made in the derivations were based on this type of vibration. The deviation among these three curves is a further indication of the nonlinearity present. Although A_r as determined from the phase angle curve was quite inaccurate, the width of the resonance curve method provides an A_r which is unexpectedly close to the value measured directly.

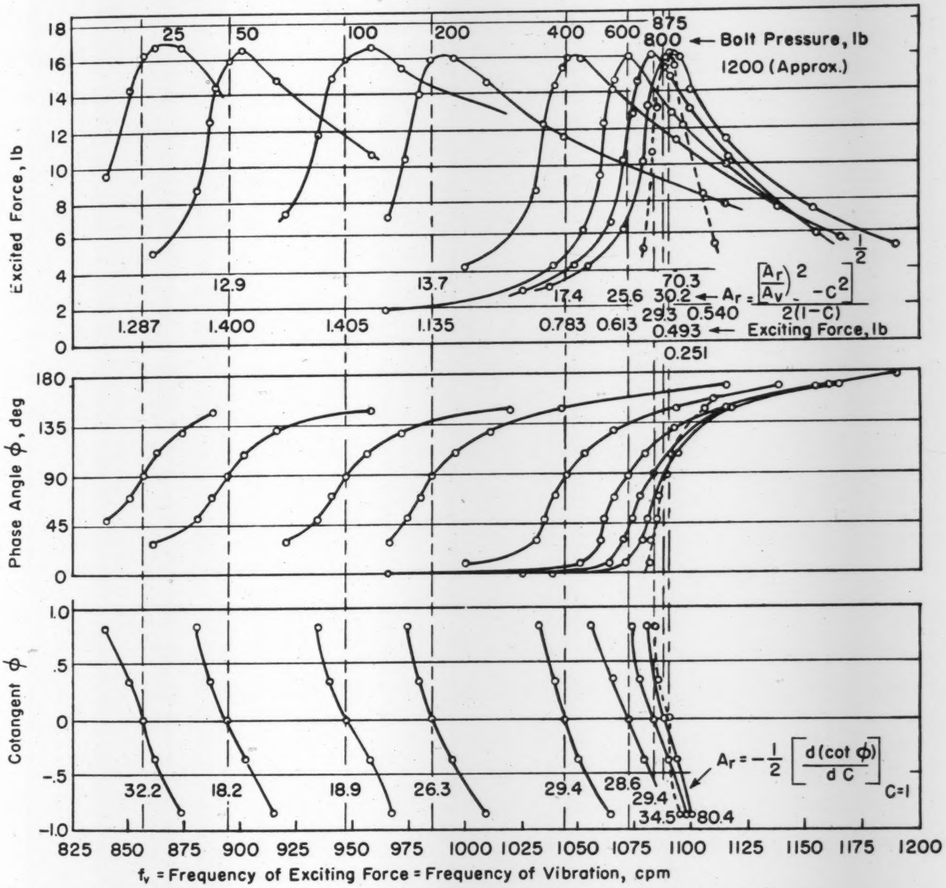

FIG. 9.—Resonance Curves for Bolted Lap Joint Without MoS_2 at Various Bolt Pressures.

In order to interpret the A_r trends shown in Fig. 10 it is desirable to discuss briefly the nature of the damping energy absorption which determines the resonance amplification factor of the joint. For purposes of discussion the energy absorbed at the friction surfaces 1–2 and 3–4 in the joint may be considered to be proportional to the product of an effective shearing force and an effective shearing motion or slip. The shearing force at dry friction surfaces may be assumed to be of the Coulomb type and therefore dependent on normal pressure only, whereas the friction on the surfaces lubricated by MoS_2 (or contaminators) may perhaps also depend somewhat on area and velocity or relative motion. In either case, however, the normal pressure will affect the frictional force. When the normal pressure is extremely large, the shearing force required to produce motion is correspondingly large, and externally applied force may be insufficient to produce significant shearing slip. Thus the product of shearing force and slip may be very small. Similarly, at very small normal and shearing force the product is small even though the magnitude of slip may be large. Thus it is apparent that at some optimum normal force both significant shearing force and slip may occur, resulting in a product which is maximum. In this region of maximum energy ab-

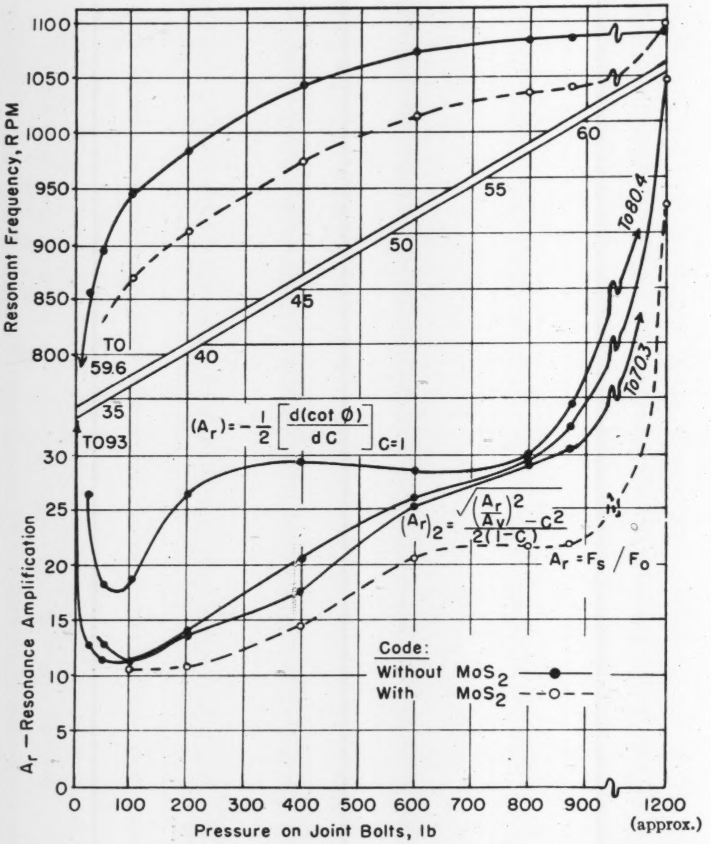

FIG. 10.—Resonance Amplification Factors and Resonant Frequencies of Joint With and Without MoS_2. A_r Determined by Three Methods.

sorption A_r will of course be a minimum. Thus, the A_r pattern shown in Fig. 10, maximum at zero and the largest bolt pressure and minimum in an intermediate region, is as expected. The decrease in A_r observed upon the addition of MoS_2 may also be rationalized on the same basis as explained above and is in agreement with previous findings (**17**). A mathematical analysis of joint damping as measured in these exploratory tests is now in progress.

SUMMARY AND CONCLUSION

The newly developed resonance vibration exciter and controller described in this paper satisfactorily accomplishes the two objectives for this machine: (*a*) to procure complete resonance amplitude and phase angle curves under both linear and nonlinear vibrations, and (*b*) to permit the determination of damping and elasticity properties during the progress of a controlled stress fatigue test. Although the basic exciter and controller may be used under several different types of stress, only its application to reversed bending vibrations is illustrated in this paper.

Equations are developed, based on the linear-damped vibration, to relate certain characteristics of the shape of the resonance and phase angle curves to the resonance amplification factor A_r. Such equations, if found reliable for nonlinear systems, would be useful in the analysis of resonance response of systems in which the exciting force is unknown, such as often occurs in practice.

Resonance response data are presented for 24S-T aluminum and mild steel. The resonance amplification factors determined from these data are found to be in reasonable agreement with A_r calculated from the damping properties determined from rotating beam damping data.

The resonance response characteristics of bolted joints are discussed and diagrammed. Variables considered in this analysis are bolt pressure and the effect of molybdenum disulfide lubricant at the friction surface. Serious nonlinearity is shown to be present in this joint, as indicated by the nonsymmetry of resonance amplitude and phase angle curves and also the nonlinearity of cotangent ϕ *versus* f_v plots. Nevertheless, A_r calculated by the width of the resonance curve method is found to be in reasonable agreement with A_r measured directly in the resonance machine. However, the slope of the contangent ϕ curve is affected apparently by the nonlinearity and thus is not a reliable indication of the resonance amplification factor.

The resonance amplification factor is found to be largest at minimum and maximum bolt pressure, reaching a minimum value at some intermediate bolt pressure. This low damping observed at maximum and minimum bolt pressure is as expected since under these conditions either the shearing slip or the shearing force, respectively, approach zero. Thus the damping energy, which is dependent on the product of effective shearing force and the effective shearing slip, is likely to approach a minimum. At some intermediate bolt pressure, however, an optimum combination of shearing force and slip motion occurs, such that the product of the two becomes a maximum.

The presence of molybdenum disulfide at the friction surfaces significantly decreases the resonance amplification factor. The general effect of a lubricant at the friction surfaces can also be rationalized on the basis of its effect on the product of the effective shearing force and the shearing slip. In the case of molybdenum disulfide, there is sufficient lubrication to decrease the shearing force, but the resultant increase in shearing slip apparently results in a larger product of the two.

Acknowledgment:

The considerable help of S. Seely, E. Codier, A. Hamberger, and I. Cogan, all of Syracuse University, in the electronic development is gratefully acknowledged. Eric Westberg of Syracuse University contributed significantly in the mechanical development and the procurement of the data on mild steel.

The cooperation of the Office of Naval Research and the U. S. Air Force, sponsors of this work, is appreciated.

APPENDIX

DEFINITION OF SYMBOLS AND TERMS, AND LISTING OF ESTABLISHED DAMPING EQUATIONS

A_r = resonance amplification factor = A_v when f_v equals f_r.

NOTE.—A paper by one of the authors (**16**) shows that $A_r = K_m \cdot K_c \cdot K_c$, where each of these three factors are a function of damping exponent ***n***.

A_r^d = resonance amplification factor under direct uniform stress = K_m.

A_v = vibration amplification factor at frequency f_v.
= ratio of amplitude of vibration near zero frequency (well below resonance) to amplitude of vibration at frequency f_v under the same exciting force.

C = discord = frequency ratio $\frac{f_v}{f_r} = 1$ at resonance.

D = unit or specific damping energy associated with a specific stress, in. lb per cu in. per cycle.

D_a = average damping energy for a given test volume.
$= \frac{D_0}{U}$, in. lb per cu in. per cycle.

D_0 = total damping energy absorbed by a test volume or a joint; in. lb per cycle.

E = static modulus of elasticity, psi.

E_d = dynamic modulus of elasticity as defined in (**14**).

F_0 = exciting force = alternating force produced by revolving eccentric, ± lb.

f_r = resonance frequency, where phase angle $\phi = 90$ deg.

F_s = force in test specimen = $A_v F_0 \pm$ lb.

f_v = frequency of the exciting force = frequency of the vibration.

J and n = constants in Eq 8 = JS^n.

K_c = cross-sectional shape factor (see **16**).

K_m = material factor = $\frac{\pi}{E_d \, JS^{n-2}}$ (see **16**).

K_s = longitudinal stress distribution factor (see **16**).

L = effective length of reduced test section of a specimen, in.

R and r = outer and inner radii of tubular specimen, in.

S = stress, psi.

U = volume of test section, cu in.

W = unit or specific elastic energy associated with a specific direct stress.
$= \frac{S^2}{2E}$, in. lb per cu in.

W_a = average elastic energy for a given test volume = $\frac{W_0}{U}$, in. lb per cu in.

W_0 = total elastic energy for a test volume, in. lb.

δ = logarithmic decrement from decay tests.
$= \log_e \frac{X_{n-1}}{X_n} \simeq \frac{\Delta X}{X_n}$,
where: X_{n-1} and X_n are amplitudes of successive decay vibrations, and $\Delta X = X_{n-1} - X_n$.

ϕ = phase angle between rotating vector representing sinusoidal exciting force and the rotating vector representing sinusoidal displacement.

ψ = ratio of damping energy to elastic energy, sometimes called specific damping capacity $= \frac{D_0}{W_0} = \frac{2\pi}{A_r} = -2\delta$ (see **4**).

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DISCUSSION

MR. E. H. SCHUETTE.[1]—While the use of long bolts and springs for applying bolt pressure to the sheet surface is certainly convenient and susceptible of close adjustment, I wonder how much bolt wobble is introduced in this way. Certainly, the bolt is freer to wobble than if it were tightened directly onto the sheet surface.

MR. B. J. LAZAN (*authors' closure*).—The holes through which the joint bolts pass provide sufficient clearance to avoid sheer contact between plates and bolts. Furthermore the magnitude of the sheering slip at the joint surfaces is relatively small; thus the bolt wobble which Mr. Schuette inquires about was insignificant.

If the bolts were tightened directly against the joint surfaces, without any intermediate springs, the control of the joint pressure variable would be extremely difficult. Thus the use of the long bolts indicated in the figures in the paper is quite essential for accurate spring preload adjustment.

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AN ELECTRON MICROSCOPE STUDY OF THE DEVELOPMENT OF FATIGUE FAILURES*

By W. J. Craig[1]

Synopsis

In the use of the electron microscope in metallography, an increase in resolving power is realized over the optical microscope. In this paper a pictorial comparison is made of deformation marks on the surface of alpha brass, ingot iron, and aluminum under both static and repeated loading. It is shown that under static loading the deformation is a general process taking place in all crystals, while under conditions of repeated loading, the deformation is an extremely localized phenomenon taking place in a few crystals or portions of crystals.

The appearance of the individual deformation marks produced by static loading as compared with those developed by repeated loading differed with the type of metal: (*a*) in alpha brass no differences were observed; (*b*) in ingot iron slight differences were observed; (*c*) in aluminum marked differences were observed.

The primary purpose of many investigators in studying the fatigue of metals has been to analyze the structural actions that occur within the polycrystalline material when repeatedly stressed. In order to evaluate the fundamental conditions influencing the behavior, fatigue studies of materials generally involve a series of mechanical tests to determine the number of cycles to fracture at various stress levels; these empirical data yield only information on the over-all behavior.

In order to learn of the structural adjustments brought about by the process of fatigue, a number of studies have been made (**1, 2, 3, 4, 5, 6, 7**)[2] to observe the initiation of slip or deformation with the aid of an optical microscope. However, these studies were limited by the ability of a lens to resolve the details of the structural changes occurring. In recent years the range of resolution or ability to see fine detail has been increased by about 50-fold through development of the electron microscope. With the present techniques of using plastic replicas of metal surfaces, it is possible to see objects whose dimensions are about 100Å units (which amounts to about 30 unit cells of the space lattice for copper or alpha brass). With this increase in ability to resolve more of the microscopic structure, a further study of the phenomena which constitute initial fatigue damage was thought desirable.

It was the purpose of this study to use the electron microscope in an attempt to extend our knowlege of the structural readjustments occurring in simple metals such as alpha iron, aluminum, and

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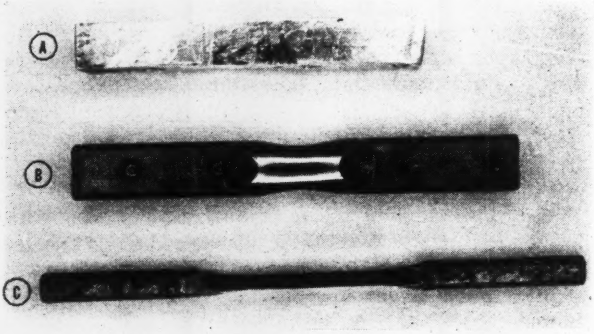
* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Research Assistant Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 889.

alpha brass. Both static and repeated load tests were investigated since it was felt that the differences in static and fatigue strengths might be explained by a comparison of the adjustments taking place under the two conditions of test.

Previous studies of fatigue by Gough, Lucas, and Moore (3, 4, 5, 6) using the optical microscope have indicated that fatigue failure is usually preceded by slip and other micro-evidences of plastic deformation even though the over-all distortion of the test member is negligible as compared with the ductility displayed in a static test. Lucas has suggested that the non-metallic inclusions represent potential sources of weakness and stepping stones which formed a path for propagation of fatigue cracks. He also noted that cyclic stressing appeared to produce disturbance in the metal surfaces in advance of a visible crack, which disturbances were highly localized in the immediate neighborhood of the crack. It was believed that further investigation of the deformation characteristics with the electron microscope might give additional information about the process of crack formation and aid in evaluating some of the present concepts of the mechanism of fatigue damage.



(*a*) Aluminum

(*b*) Ingot Iron

(*c*) Alpha Brass

FIG. 1.—Fatigue Test Specimens.

MATERIALS STUDIED AND METHOD OF TESTING

In order to minimize the complexity of the deformation processes that might be encountered in metals with many complex alloy phases, it was decided to select several polycrystalline metals that were primarily of a single phase constitution. Alpha brass was selected as a single phase metal and the material used was from bar stock that had been employed on other studies of mechanical strength properties (8). Tests were also made on ingot iron because it is the primary constituent in steel and thus is representative of the behavior of a weaker constituent, even in heat-treated steels containing various amounts of carbon. It was felt that the mechanism of fatigue would be the same in alpha iron as that of ferrite in steel. Tests were also made of a laboratory prepared pure aluminum (99.97 per cent) to determine the behavior of the primary constituent existing in the aluminum alloys. Aluminum is also representative of a different type of crystal lattice than that of the alpha iron.

The aluminum and the alpha iron were treated to produce very large crystals in the hope that this would magnify the scale of the basic deformation process and thus make it easier to observe the fatigue damage than would be the case for the normal fine-grained structure. Another factor in the selection of these materials was the necessity of selecting metals that could be readily electropolished to remove cold-worked surface layers and to prepare a smooth suitable surface for studies of deformation from which plastic replicas could be stripped for use in the electron microscope.

Details of the fatigue test specimens are illustrated in Fig. 1. These specimens were subjected to completely reversed cycles of flexural stress in a Krouse vibratory-bending type of fatigue machine. They were thus stressed as cantilever beams with the maximum stress occurring on the extreme fiber near the fixed end of the beam. The specimens were repeatedly stressed for various numbers of cycles at nominal stresses computed from the ordinary flexure formula $s = Mc/I$. For a given number of cycles of stressing, the bending moment varied linearly from one end of the specimen to the other; hence, even though the specimen fractured near one end, replicas could be made of areas subjected to the same number of cycles of a lower stress magnitude.

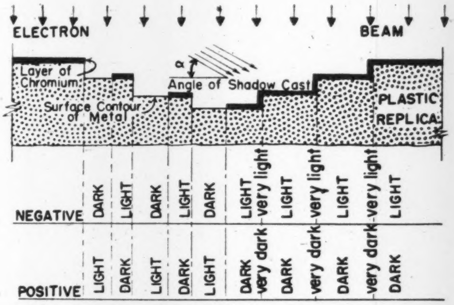


FIG. 2.—Schematic Diagram of Shadow-Cast Plastic Replica in Relation to Photographic Reproduction.

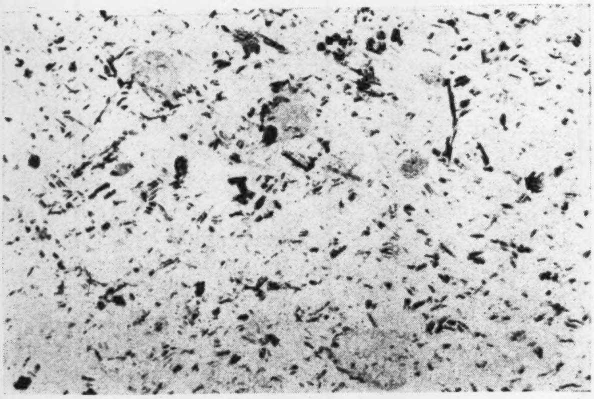
The specimens were prepared with as strain-free a condition as possible by annealing after the machining operations had been performed. The surface effects (oxidation, etc.) developed during the annealing operation were removed by using fine metallographic polishing papers followed by electropolishing in suitable electrolytes. The majority of fatigue tests were conducted with the surface in the electropolished condition without etching. It was found that an etched surface did not show the effects of localized deformations as readily as an unetched electropolished surface.

Minute fatigue cracks were developed in the test specimens by repeatedly stressing at a level just above the fatigue strength. The specimens were examined periodically to determine whether slip bands had developed or to determine to what extent visible or microscopic cracks might be present. The electropolished surface was such that the structural details and grain boundaries were not visible prior to the repeated stressing. After stressing, relief of the surface in localized zones was used as evidence of the deformation occurring in the crystalline structure.

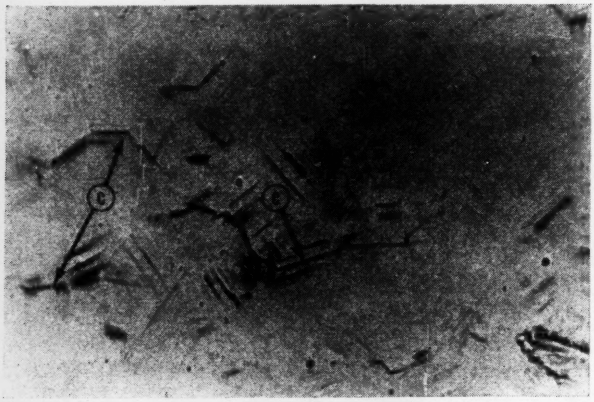
OBSERVATIONS OF DEFORMATION IN METALS

The technique of utilizing the electron microscope for determining the metallographic structure and deformational characteristics has been described in a recent article (9). However in order to clarify the interpretation of electron micrographs, a review of the fundamentals of the procedure might be desirable. Briefly, the electron micrograph is made from a very thin plastic "casting" or replica of the surface of the metal. The electron beam in the microscope is caused to traverse through the thickness of this replica; variations in thickness cause variations in the intensity of the beam recorded on a photographic film. However, the thin replica is lacking in density contrast and in this work all of the replicas have been "shadow cast" with chromium atoms to increase the contrast. That is, the evaporating of metallic atoms from a heated filament in a vacuum deposits chromium on the replica in a manner which depends on the angle at which the chromium is cast.

The resulting effect can best be visualized by considering the schematic diagram in Fig. 2. In this diagram the contours of the surface of a replica represent the irregularities of the metal surfaces from which the replica was cast. The chromium will build up a deposit on the front faces of the protrusions and leave chromium-free or "shadow" areas on the leeward side of these protruding "hills." Thus when the electron beam is later passed through the replica, it will be stopped by the dense chromium deposit leaving a light area on the photographic negative; the electron beam passes readily through the "shadow" areas and produces a black area on the photographic negative. When photo-



(*a*) (× 200). Reduced one half in reproduction.



(*b*) (× 1000). Reduced one half in reproduction. Cracks evident at points "C."

FIG. 3.—Photomicrographs of Areas Near Fracture.

Alpha brass fatigue specimen (A-11) stressed at 23,000 psi for 1,023,000 cycles.

graphic prints are made from these negatives, the light and dark are reversed. Hence, in the micrographs reproduced in this report the dark areas represent raised portions of the replicas that were built up with a chromium deposit whereas the light areas represent the "shadow" in which little or no chromium was deposited.

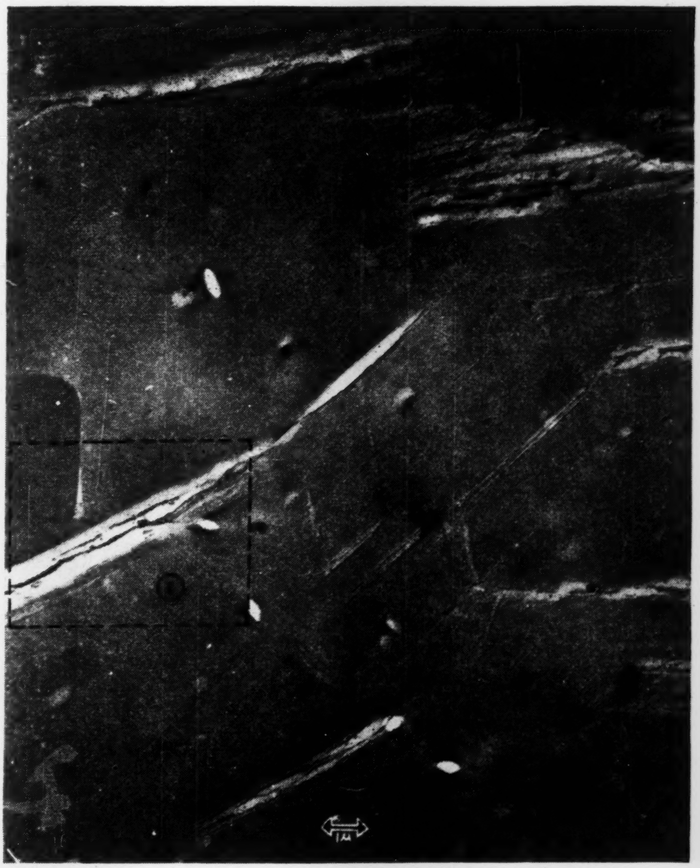


FIG. 4.—Electron Micrograph of Alpha Brass (× 11,000).
Reduced one half in reproduction. From a portion of the area shown in Fig. 3(*a*).

The heights of surface irregularities may be calculated from measurements of the length of shadows and from the angle of shadow casting. Also, the electron micrographs may be more easily interpreted by the metallographer if he assumes the perspective of being inside the metal looking toward the metal surface. All of the electron micrographs shown in this paper were made from negative parlodion replicas shadow-cast with chromium at an angle α (Fig. 2) of about 18 deg.

Micrographs of Alpha Brass:

In Fig. 3 is shown the structure of the surface of a specimen of alpha brass of the region near a fatigue crack which resulted in fracture of the specimen. In optical metallographs at 200× and at 1000× deformation of the surface is localized in fragmented bands. The cracks appear to grow from these localized deformations in which it appears that considerable slip or fragmentation has taken place. Electron micrographs of this same general area (Figs. 4 and 5) indicate that the deformation under repeated loading is highly localized even to the extent that in one grain or crystal there appears to be one or more highly localized areas of deformation or fragmentation. An analysis of the electron micrograph in Fig. 5 (which covers portion C of Fig. 4 at higher magnification) indicates that the contour of the surface from *A* to *B* changes as illustrated in the diagram in Fig. 6.

From observations of a number of brass specimens the evidence indicates that a fatigue failure begins in small isolated zones where the load on a crystal (or a portion of a crystal) has been great enough to cause excessive deformation to concentrate in a localized region or band. One observes that the surrounding regions and neighboring crystals may show no visible evidence of slip or other plastic deformation even

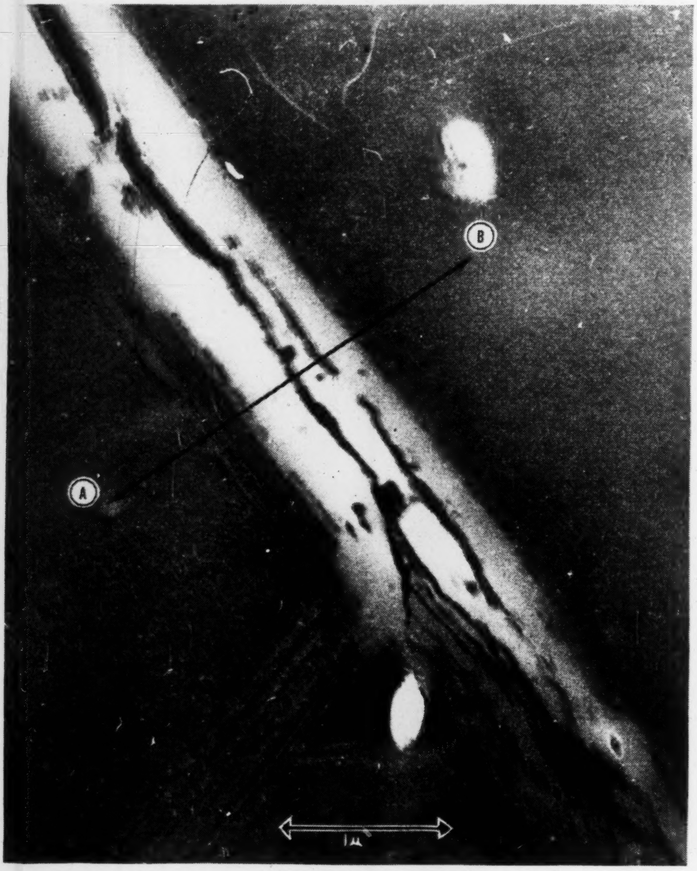


FIG. 5.—Electron Micrograph of the Region "C" of Fig. 4 (× 41,000). Reduced one half in reproduction.

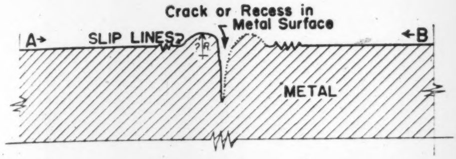


FIG. 6.—Sketch of Contour of Surface of Fragmented Area in Alpha Brass Along Section A to B Shown in Fig. 5.

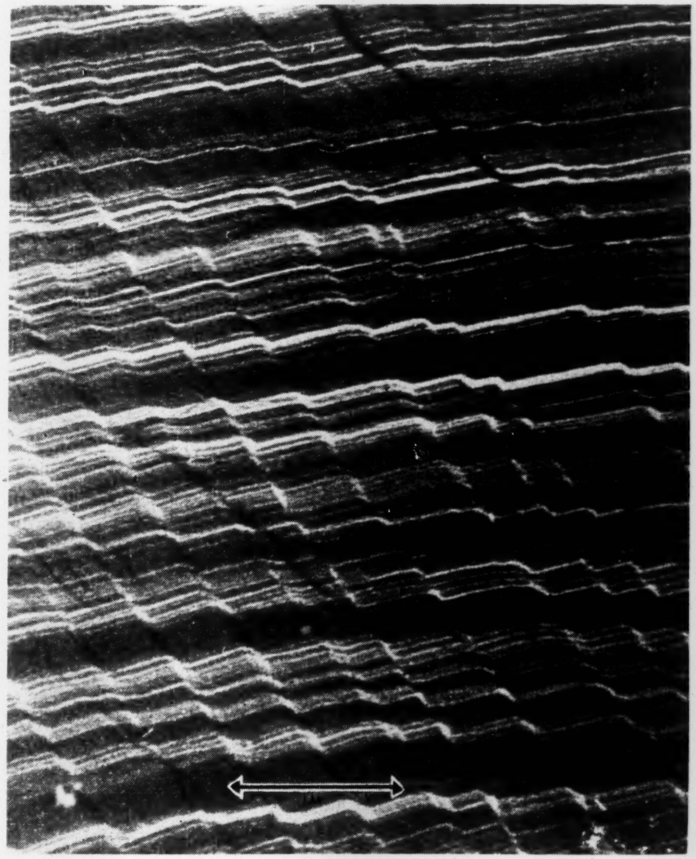


FIG. 7.—Electron Micrograph of Surface of Tension Specimen of Alpha Brass Which Was Strained to Maximum Load (× 41,000). Reduced one half in reproduction.

The minimum spacing of primary slip markings is about 100Å. Average spacing of secondary slip is about 4500Å.

after fatigue cracks have developed. The localized inelastic deformation is not enough to relieve the load on the crystals which have yielded; on each reversal of stress it appears that the deformation continues in these concentrated zones and gradually progresses to a greater extent until fragmentation reaches a limit. Perhaps when localized fragmentation becomes excessive, the energy from further loading cycles tends to disrupt completely the atomic bonds, producing minute fatigue cracks. Failure often begins in more than one crystal at a time and at more than one place in a single crystal or grain. The final evolution of a visible fracture apparently consists in developing several of these microscopic cracks to an extent such that they join and thence the progress of failure appears at a more rapid rate.

In order to compare the appearance of deformation marks under repeated loading with those from static loading, an electron micrograph of alpha brass from a tension specimen (after straining to maximum load) is shown in Fig. 7. Here one observes that the deformation is extensive throughout the crystalline grain whereas under repeated loading the deformation is extremely localized within portions of only a few crystals. However it is of interest to note that the minimum spacing observed between neighboring slip bands under static loading and that measured under repeated loading was the same (about 100Å to 125Å); However, the lower limit of resolution of the console-type electron microscope used is about 100Å units. Hence, if slip occurs in small steps by spacings closer than this amount, the electron microscope is not capable of resolving this finer detail and, hence, a limit is reached on the ability of the

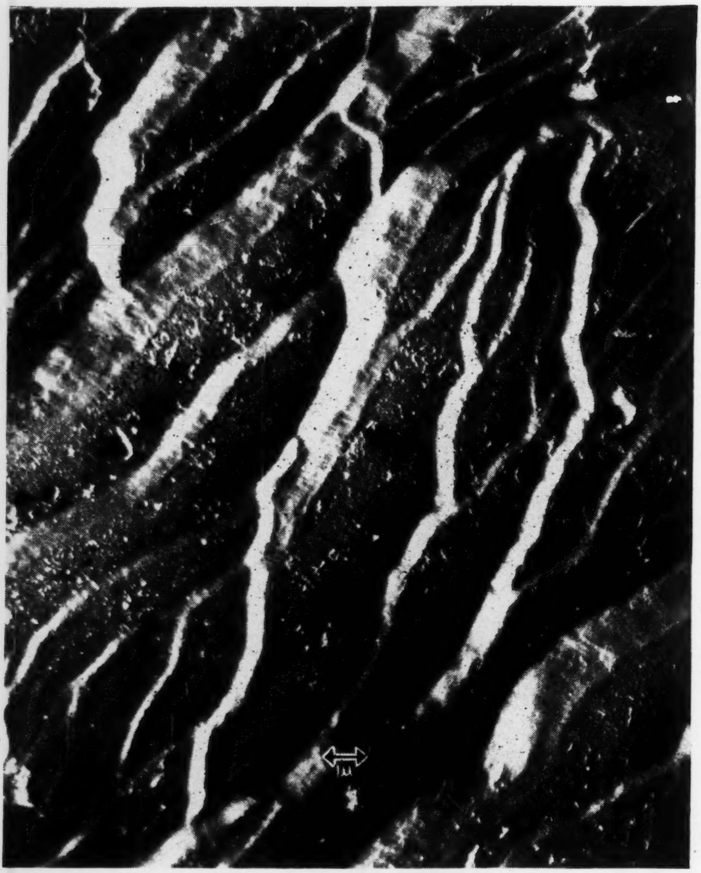


FIG. 8.—Electron Micrograph of Ingot Iron Stained 10 per cent in Static Tension (× 11,000). Reduced one half in reproduction.

The wavy pattern of deformation probably results from simultaneous slip on three slip systems.

equipment to make the deformation visible.

Alpha Iron:

A typical electron micrograph of the deformation marks developed in alpha iron by static tensile loading is shown in Fig. 8. The evidence indicates that the deformation is as extensive and of a more irregular nature than that observed for brass and aluminum. However under repeated loading conditions, the deformations were again localized and fatigue failures were found to initiate from localized deformation bands as indicated in electron micrograph (Fig. 10).

Complete fracture of the test specimen results from the progressive growth of one or more micro-cracks. In some instances numerous nuclei will be generated (at high stress levels) in a number of crystals in neighboring regions. These cracks progressively grow with the repeated stressing until they join with the small cracks in neighboring crystals as shown in Fig. 9 and then proceed at an accelerated rate of growth. However it may be possible to develop a micro-crack in an isolated crystal which does not grow or join other small cracks to complete fracture of the specimen. While the resolving power of even the electron microscope is not sufficient to determine the exact cause of crack initiation, there is good evidence in the materials examined that the initial cracks seem to grow (Fig. 10) from local deformed or fragmented paths that follow the general direction of slip bands on the surface. While these streaks have the general directions of slips bands, they are of much greater width and appear to be much more rippled and fragmented on the surface than would be the case for a deformation consisting only of simple slip as visualized by the process of propagation of simple dislocations.

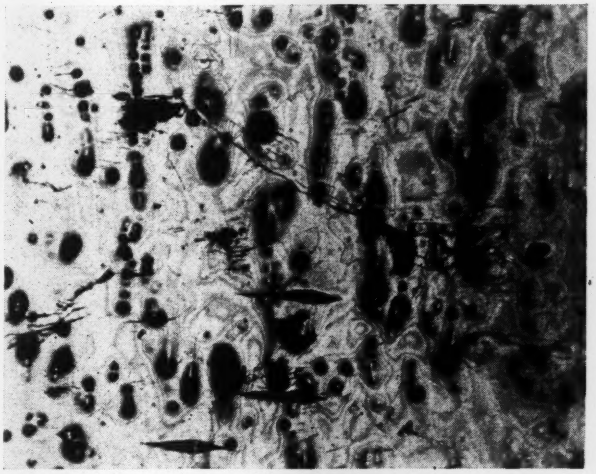


FIG. 9.—Photomicrograph of Ingot Iron After Repeated Stressing. Specimen stressed at 24,900 psi for 744,000 cycles (× 200). Reduced one half in reproduction.

Concentrated deformation marks are initiated at many locations. The Knoop indents were used for reference marks (Newton rings caused from thin film of parlodion on specimen).

Micrographs of Aluminum:

A typical micrograph of the aluminum after repeated stressing is shown in

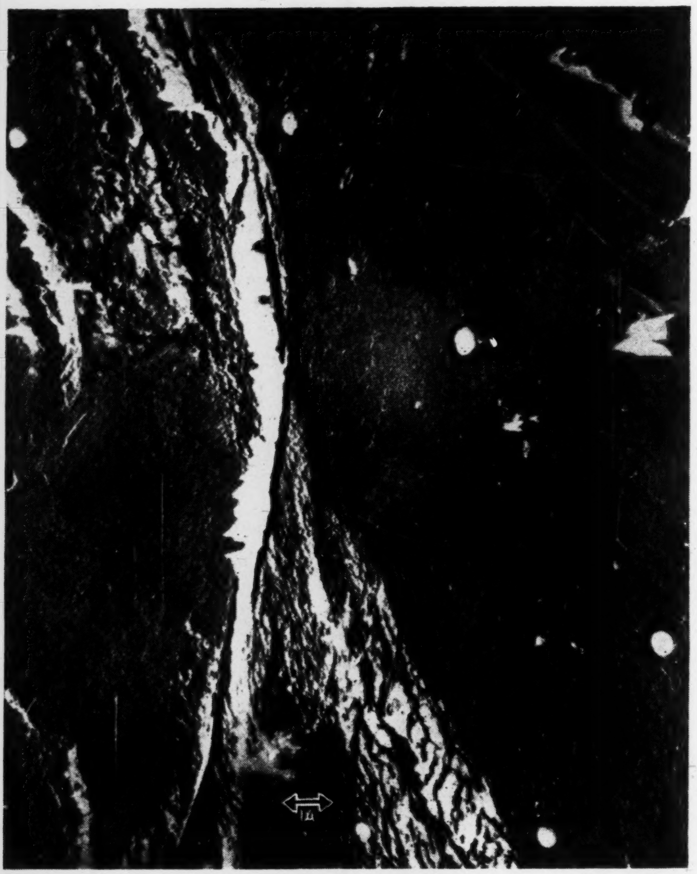
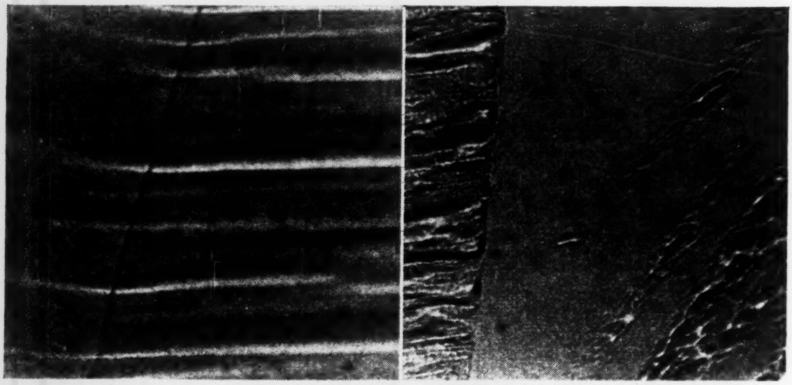


FIG. 10.—Electron Micrograph of Ingot Iron (taken from area near Knoop indents in Fig. 9) (× 11,000). Reduced one half in reproduction.

Dark line indicates a submicroscopic crack growing out of a region of deformation.



(*a*) After about 3 per cent static strain. (*b*) After repeated bending at 1500 psi for 52 million cycles.

FIG. 11.—Photomicrographs of Aluminum Strained Statically and Dynamically (× 2400). Reduced one half in reproduction.

Fig. 11(*b*). While repeatedly stressing, the deformation marks which show on the surface develop by progressive extension until a crack appears. During the spread of this localized plastic action, the surface becomes so distorted that the details of the action taking place in the later stages is obscured. It is difficult to determine at what stage a crack begins to grow in the distorted region. It will be noted in Fig. 11 that the deformation marks have a somewhat different appearance and all of the surrounding region is more uniformly distorted by plastic slip and deformation in the specimen strained statically.

It was not possible to strip replicas from highly distorted areas in the aluminum specimens but replicas could be obtained from areas near the edge of the highly distorted region. In Fig. 12 is illustrated an electron micrograph of the deformation occurring in a zone near the fracture but just at the edge of the highly distorted region. For comparison with this fatigue specimen there is reproduced in Fig. 13 an electron micrograph of the deformation markings produced under static loading.

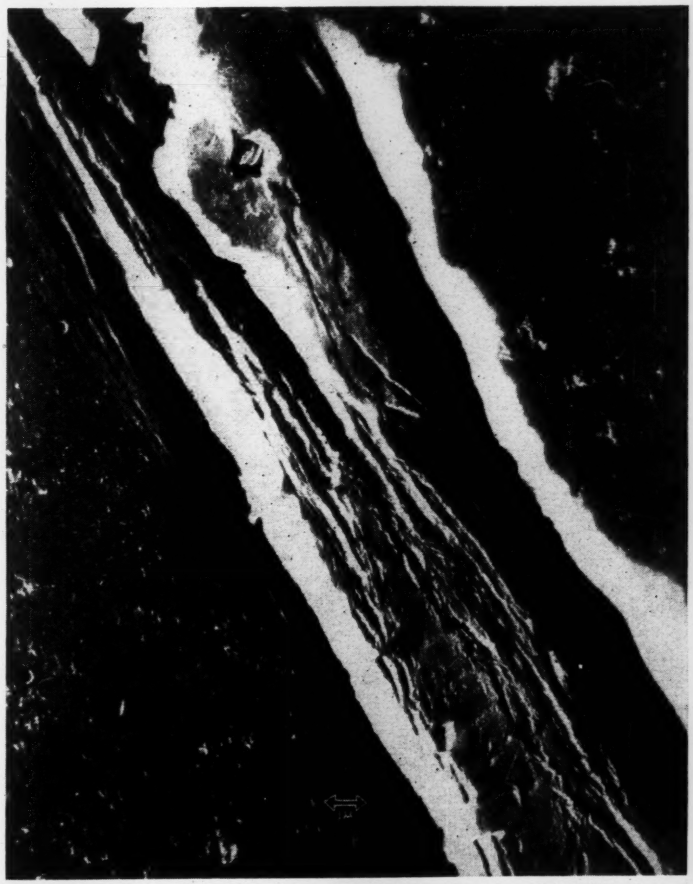


FIG. 12.—Electron Micrograph of Deformation Marks Developed in Aluminum by Repeated Bending (× 11,000). Reduced one half in reproduction.

Same area as shown in Fig. 11(*b*).

CONCLUSIONS

The micrographs of brass stressed either statically or dynamically indicate the deformation marks to have somewhat the same appearance; that is, the minimum spacings of deformation or slip are about the same. However, the brass under static tension deforms by slip throughout the crystals whereas under repeated loading, the deformation is extremely localized and the extent of deformation varies within the crystals as well as throughout the specimen.

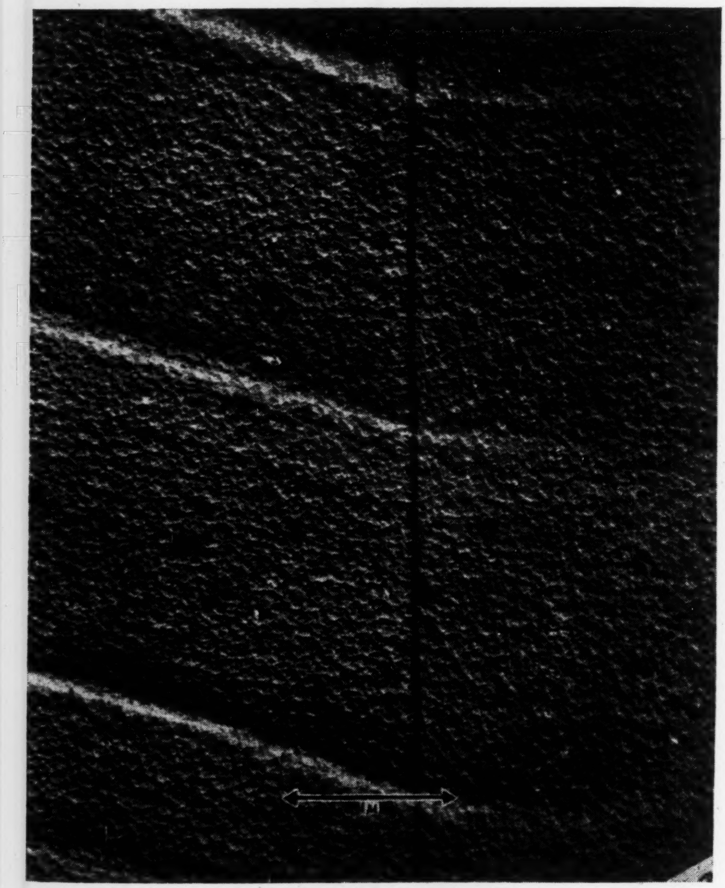


FIG. 13.—Electron Micrograph of Deformation Marks in Aluminum Strained About 3 per cent by a Static Load (× 41,000). Reduced one half in reproduction.
Same area as shown in Fig. 11(*a*).

The ingot iron appears to deform by producing a wavy pattern as if several slip systems are operating at one time; this is the same conclusion arrived at by other investigators. When ingot iron is stressed repeatedly, the deformation marks appear to be extremely localized but have somewhat the same appearance as those produced by static tension.

Micrographs of deformation marks formed by static tension in aluminum do not have the same appearance as those formed by repeated loading.

Though aluminum and brass theoretically deform on the same crystallographic planes, the surface deformations developed do not have the same appearance.

Acknowledgment:

This investigation was conducted in the Department of Theoretical and Applied Mechanics at the University of Illinois as a part of research project NR-031-005 sponsored by the Office of Naval Research, U. S. Navy. Appreciation is expressed to the Metallurgy Branch, Office of Naval Research for their continued interest in and support of this project.

The author is especially indebted to Professor T. J. Dolan for his guidance and supervision in this investigation and assistance in preparing this paper. Appreciation is also expressed to V. G Peck whose knowledge of electron microscopy made the investigation possible and to the Chemistry Department for furnishing facilities for making electron micrographs. Mr. C. Edward Swanson assisted in the preparation of figures presented in this report.

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THE CREEP PROPERTIES OF SAND-CAST ALUMINUM MATERIALS 319-T71, 319-F, AND 356-T7*[1]

By O. D. Sherby[2] and J. E. Dorn[2]

Synopsis

The creep and stress-rupture properties of 319-T71, 319-F, and 356-T7 sand-cast aluminum alloy materials were determined over the range of temperatures from 90 to 400 F and for times under stress up to 1000 hr. At 90 F the solution-heat-treated, precipitation-hardened, and stabilized 319-T71 material exhibited the highest creep resistance, the as-cast 319-F material was intermediate and the solution-heat-treated and precipitation-hardened 356-T 7 had the least creep resistance. At 400 F, however, 319-F had the greatest creep resistance, 319-T71 was intermediate, and 356-T7 showed the least creep resistance. The inversion in the order of merit of the two tempers of 319 alloy with increasing test temperature is probably ascribable to the higher creep resistance of the solution heat-treated, precipitation-hardened, and stabilized state of the 319-T71 material as contrasted with that of the 319-F as-cast material at the lower test temperatures and to the resulting decrease in the creep resistance of 319-T71 material as contrasted with that of the 319-F material at elevated temperatures where continued overaging of the 319-T71 material might occur and thereby induce higher creep rates.

Extensive data are now available on the creep characteristics of numerous rolled (**1, 2, 3, 4**)[3], extruded (**5**), and forged aluminum alloys (**6**) in various cold-rolled annealed, and heat-treated states. Up to the present only a limited amount of information is available on the creep characteristics of aluminum alloy castings (**6**). This investigation was initiated to uncover additional data on the creep characteristics of aluminum alloy sand castings.

Creep tests were made on 319-T71, 319-F, and 356-T7 sand-cast aluminum alloy materials at temperatures of 90 to 400 F and times of stressing up to 1000 hr. Secondary creep rates approximating as low as 10^{-7} per hr were obtained.

Materials and Specimens

The materials used for test were prepared by the Aluminum Company of America in accordance with the best commercial practice of melting, casting, and heat-treating. All test bars of each alloy and temper were cast from the same heat of metal into ½-in. diameter test bars in

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] The ASTM designations for the alloys considered in this paper are:

Commercial Designation	ASTM Designation
319	SC64C
356	SG70A
142	CN42A
195	C4A
B214	GS42A
355	SC51A
A355	...

[2] Research Engineer and Professor of Metallurgy, respectively, University of California, Berkeley, Calif.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 902.

accordance with ASTM specifications.[4] The chemical composition of the alloys is given in Table I. In Table II the various heat-treatments which were given to the alloys are recorded, and in Table III are summarized the mechanical properties and grain size of each alloy and temper.

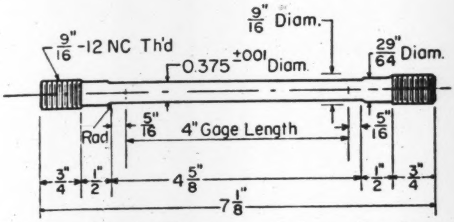

FIG. 1.—Stress—Rupture and Creep Specimen.

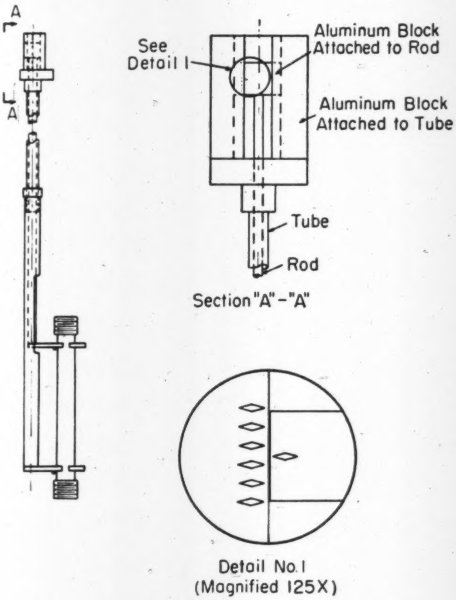

FIG. 2.—Schematic Illustration of Extensometer and Method of Attachment to Creep Specimen.

In order to achieve sufficiently high stresses for the creep investigations on existing equipment, it was necessary to employ specimens having a diameter of $\frac{3}{8}$ in. Such creep specimens were machined from the cast $\frac{1}{2}$-in. diameter bars to the design shown in Fig. 1.

The data recorded in Table I reveal that the chemical compositions of the three materials investigated are well within the specified values. The tension test values given in Table III show that the properties of both the $\frac{1}{2}$-in. diameter tension bar and the $\frac{3}{8}$-in. diameter creep specimen of each alloy and temper tested fall within the specified limits and agree closely with the typical values. The materials tested had grain sizes which were typical of sand-cast aluminum alloys. Metallographic examination also revealed that the microstructures were typical for the alloys and tempers which were studied. X-ray examination indicated all of the bars which were tested were radiographically sound.

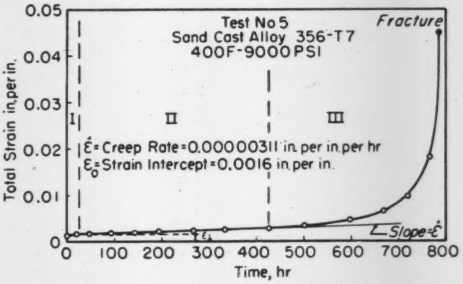

FIG. 3.—Typical Creep Curve for Aluminum Cast Alloys.

EXPERIMENTAL TECHNIQUE AND TESTING PROCEDURE

The creep equipment and testing procedures used in the present investigation were essentially the same as those which have been reported previously (1, 6). Minor changes on the creep-testing machines included the use of new lever arms having a ratio of 15 to 1 in order to obtain sufficiently high stresses for the creep of the $\frac{3}{8}$-in. diameter round bars.

In order to increase the sensitivity of the strain measurement new extensome-

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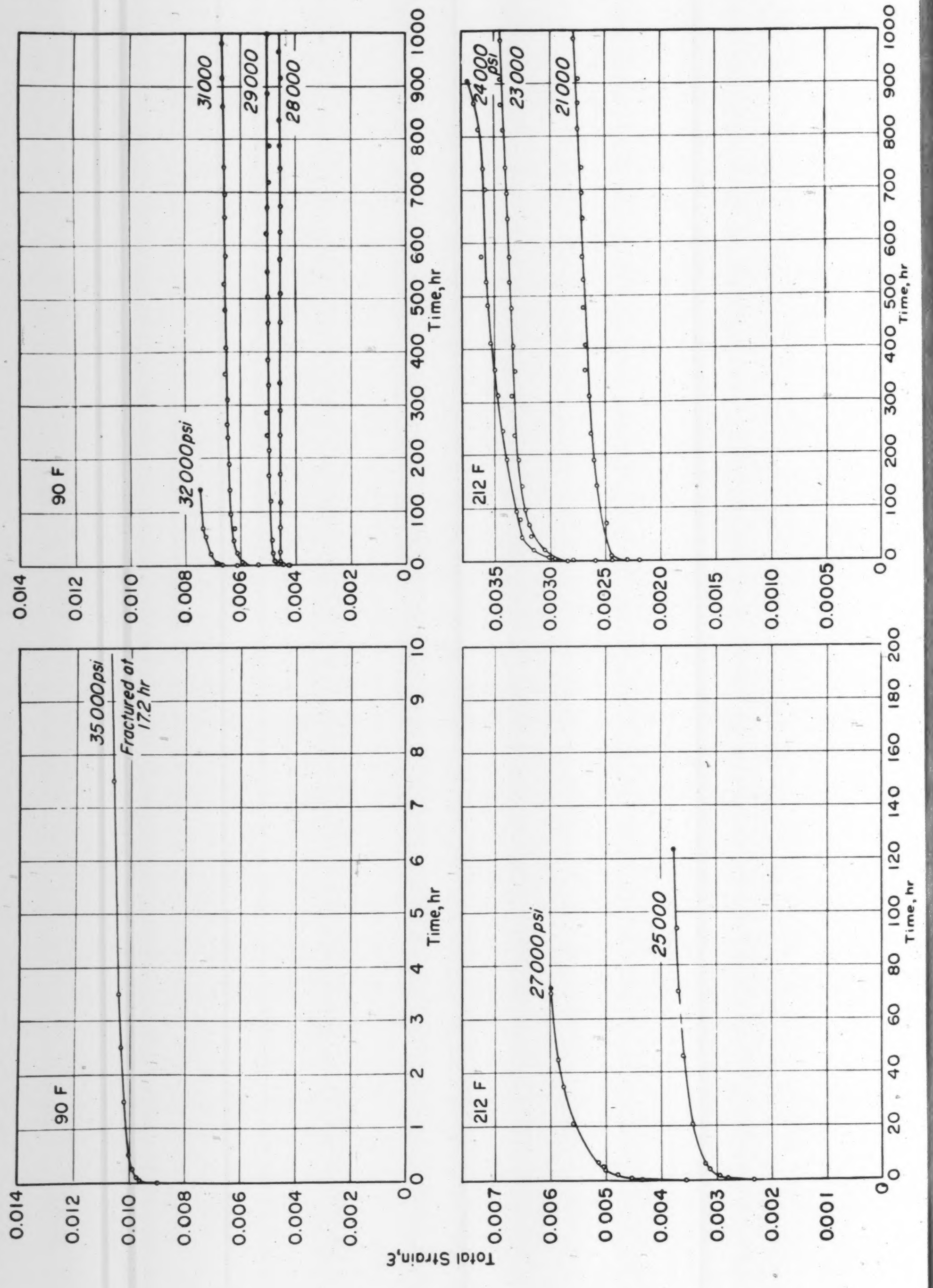
[4] Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 50 T), 1950 Supplement to Book of ASTM Standards, Part 2, p. 140.


Total Strain, ε
90 F
35000 psi
Fractured at 17.2 hr
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0
0 1 2 3 4 5 6 7 8 9 10
Time, hr
90 F
32000 psi
31000
29000
28000
0 100 200 300 400 500 600 700 800 900 1000
Time, hr
212 F
27000 psi
25000
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0 20 40 60 80 100 120 140 160 180 200
Time, hr
212 F
24000 psi
23000
21000
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0
0 100 200 300 400 500 600 700 800 900 1000
Time, hr

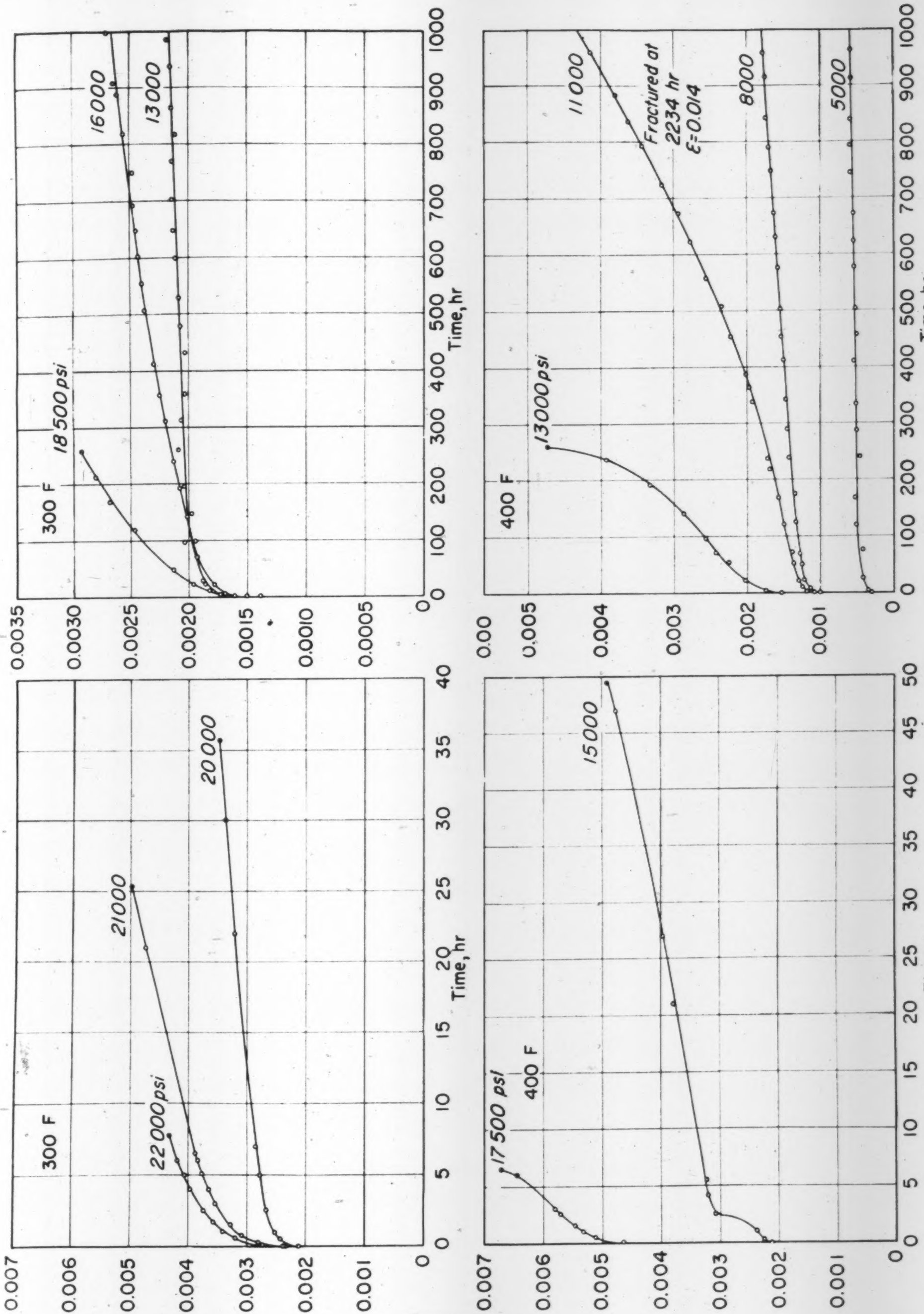
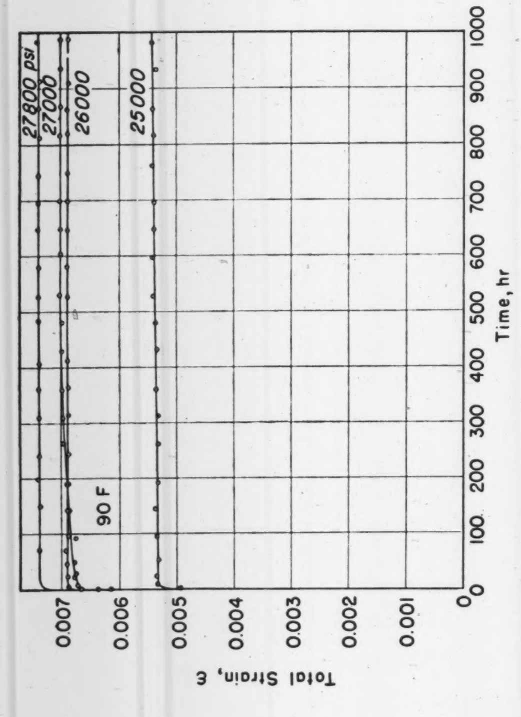
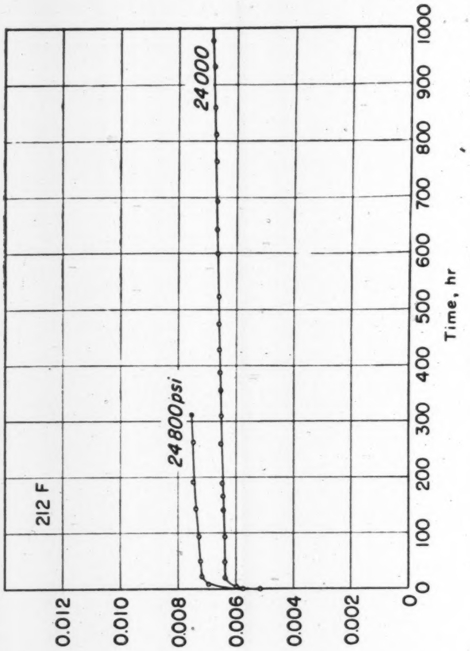
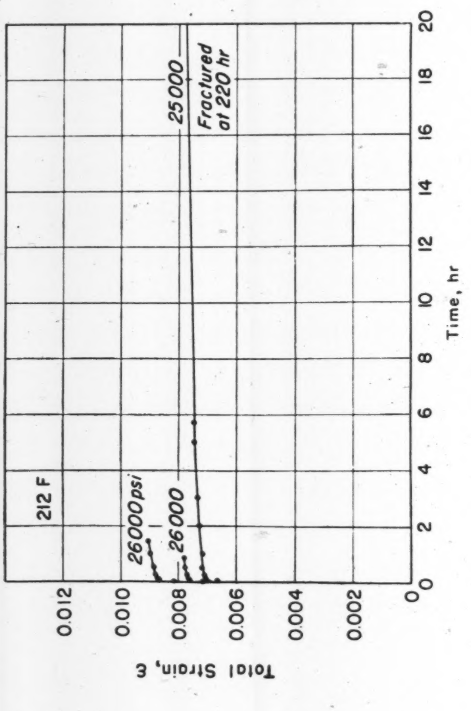


FIG. 4.—Total Creep Strain as a Function of Time for Sand-Cast Material 319-T71 at 90, 212, 300, and 400 F.


90 F
27800 psi
27000
26000
25000
Total Strain, ε
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
Time, hr
0
100
200
300
400
500
600
700
800
900
1000


212 F
24800 psi
24000
0
0.002
0.004
0.006
0.008
0.010
0.012
Time, hr
0
100
200
300
400
500
600
700
800
900
1000


212 F
26000 psi
26000
25000
Fractured at 220 hr
Total Strain, ε
0
0.002
0.004
0.006
0.008
0.010
0.012
Time, hr
0
2
4
6
8
10
12
14
16
18
20

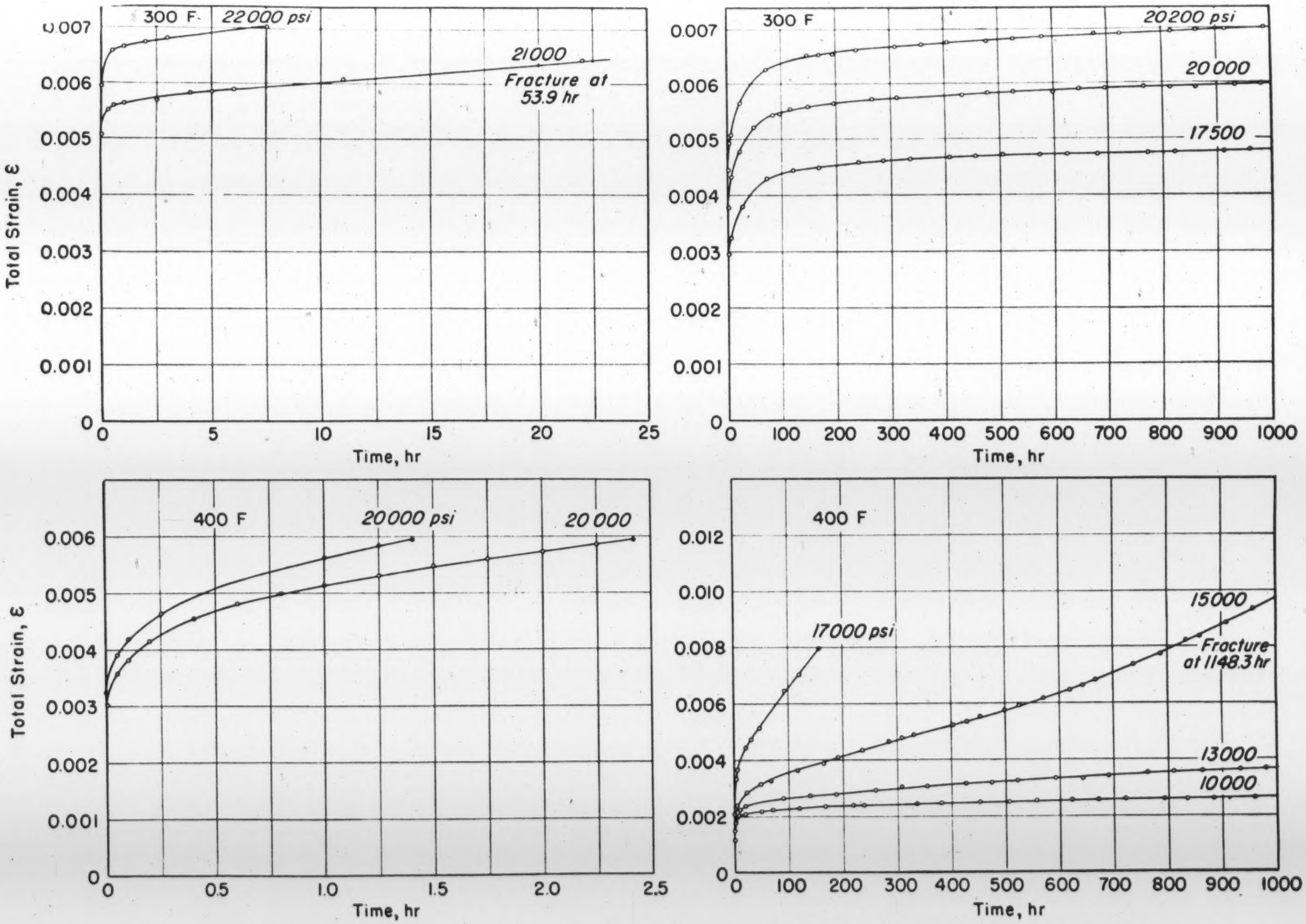
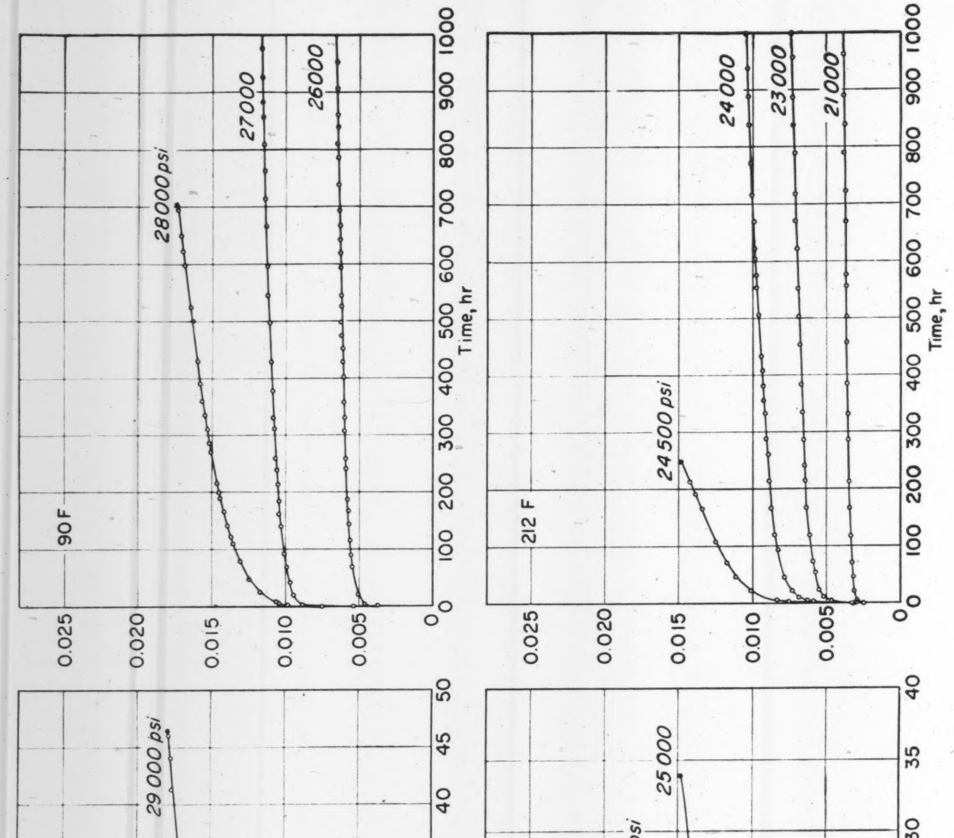


FIG. 5.—Total Creep Strain as a Function of Time for Sand-Cast Material 319-F at 90, 212, 300, and 400 F.


90 F
28000 psi
27000
26000
0
0.005
0.010
0.015
0.020
0.025
0
100
200
300
400
500
600
700
800
900
1000
Time, hr
212 F
24500 psi
24000
23000
21000
29000 psi
0
5
10
15
20
25
30
35
40
45
50
25000 psi
25000
Total Strain, ε

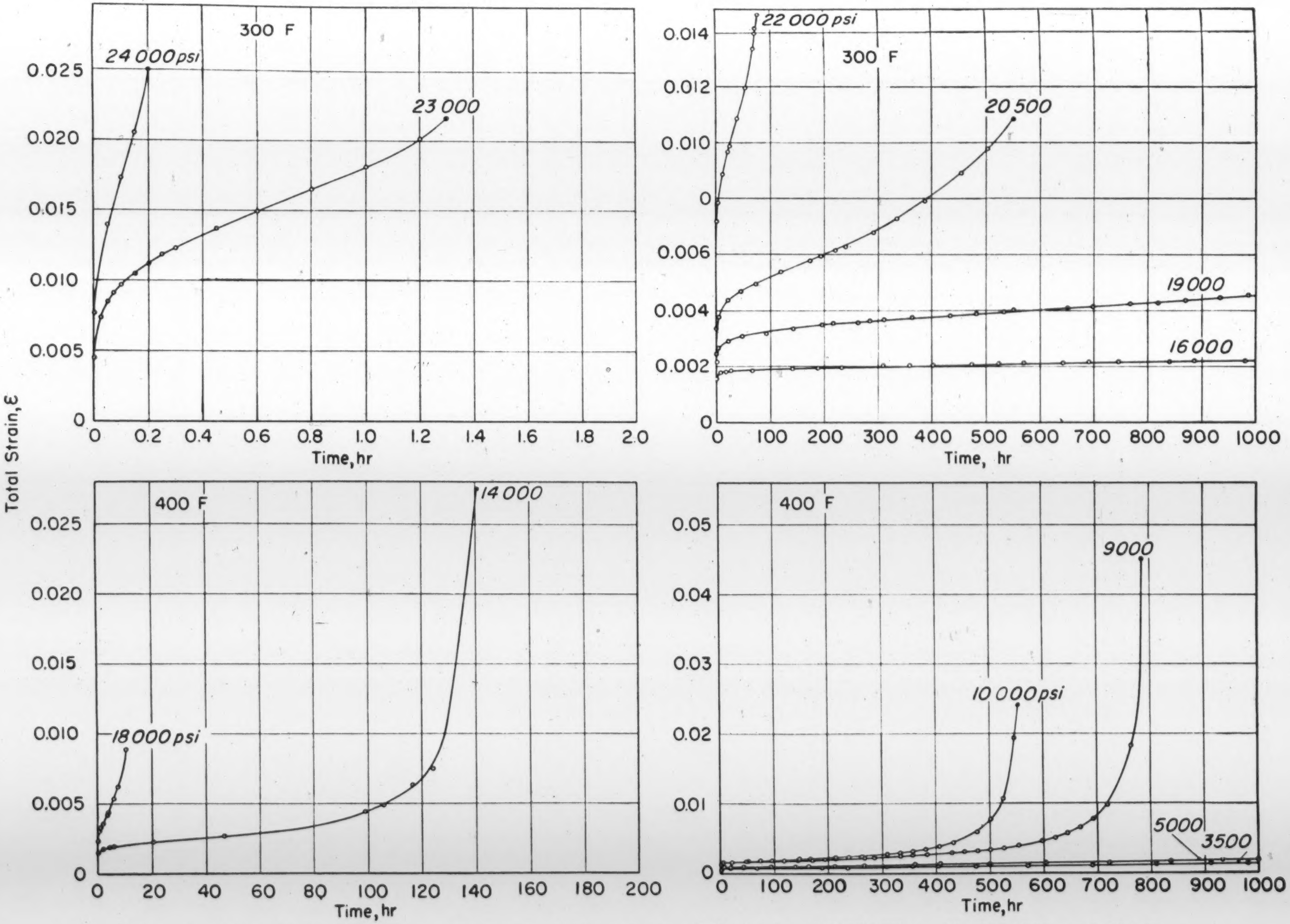


FIG. 6.—Total Creep Strain as a Function of Time for Sand-Cast Material 356-T7 at 90, 212, 300, and 400 F.

ters of the design shown in Fig. 2 were developed. The extensometer consists of a rod, attached to the upper gage point of the specimen, which slides in a tube attached to the lower gage point of the specimen. Firm gripping of the extensometer to the specimen is achieved by spring clamping the hardened and ground knife edges, which are attached to the bottom of the rod and to the bottom of the tube, to the specimen at the gage points. Any extension in the gage section of the specimen, therefore, yields an identical relative displacement of the two polished aluminum blocks attached to the upper ends of the tube and rod, respectively. A single reference Tukon impression was made at the left edge of the inner block as shown in Detail 1 of Fig. 2. A series of Tukon impressions spaced approximately 0.013 in. apart was placed on the adja-

TABLE I.—CHEMICAL COMPOSITION[a] OF THE SAND-CAST MATERIALS INVESTIGATED.

	Chemical Composition, per cent									Other Elements	
	Copper	Iron	Silicon	Manganese	Magnesium	Zinc	Chromium	Nickel	Titanium	Each	Total
Alloy 319-T71											
Nominal	3.5	...	6.3	...	...	...	...	...	...	...	...
Specified	3.0–4.5	<1.2	5.5–7.0	<0.8	<0.5	<1.0	...	<0.5	<0.2	...	0.05
Actual	3.58	0.58	6.06	0.35	0.13	0.68	...	0.30	0.03	...	<0.05
Alloy 319-F											
Nominal	3.5	...	6.3	...	...	...	...	...	...	...	...
Specified	3.0–4.5	<1.2	5.5–7.0	<0.8	<0.5	<1.0	...	<0.5	<0.2	...	0.05
Actual	3.67	0.73	6.30	0.49	0.14	0.69	...	0.32	0.03	...	<0.15
Alloy 356-T7											
Nominal	...	...	7.0	...	0.3	...	...	...	...	...	...
Specified	0.2	<0.6	6.5–7.5	<0.3	0.2–0.4	<0.3	...	...	<0.2	<0.05	<0.15
Actual	0.02	0.29	7.32	0.01	0.36	0.02	...	...	0.11	<0.05	<0.05

[a] Nominal values were obtained from Alcoa Aluminum and its Alloys; specified values were obtained from ASTM Specifications B 26 – 48 T and B 108 – 49 T; and actual analyses were made by the Aluminum Company of America.

TABLE II.—HEAT TREATMENTS.

319-T71	Solution heat-treated at 940 F for 12 hr; water quenched; overaged and stabilized by holding at 475 F for 5 hr.
319-F	As cast.
356-T7	Solution heat-treated at 1000 F for 12 hr; water quenched; precipitation hardened to maximum hardness by aging at 440 F for 4 hr.

TABLE III.—MECHANICAL PROPERTIES AND GRAIN SIZE.

Alloy and Temper	Properties[a]	Diameter of Tension Specimen, in.	Tensile Strength, psi	Yield Strength, 0.2 per cent offset, psi	Elongation in 4D, per cent	Brinell Hardness Number	Grain Size, grains per mm
319-T71	Typical[c]	½	37 000	34 000	1.0	90	
	Specified[c]	½	30 000	...	...	...	
	Actual[d]	½	37 900	29 000	1.0	88	1
		⅜	35 100	30 800	1.0	...	
319-F	Typical	½	27 000	18 000	2.0	70	
	Specified	½	23 000	...	...	...	
	Actual	½	29 300	22 400	1.0	82	0.5
		⅜	28 400	22 700	1.3	...	
356-T7	Typical	½	34 000	30 000	2.0	75	
	Specified	½	31 000	...	...	...	
	Actual	½	32 200	26 500	3.5	68	0.6
		⅜	31 100	26 400	2.0	...	

[a] Except as noted otherwise, the typical and specified values are from Alcoa Aluminum and Its Alloys, 1947 Edition.

[b] 500-kg load on 10-mm ball for 30 sec.

[c] Tentative values.

[d] The actual data were determined by the Aluminum Company of America.

cent edge of the outer aluminum block. The distance between each Tukon impression was carefully calibrated to the nearest 0.00001 in. by means of a microscope.

Interpolation of the distance between two successive Tukon impressions was accomplished by means of a 125 power microscope having a cross-hair micrometer. Using a 4-in. length over a total strain of 0.20, this equipment was found to be sensitive and reproducible to strains of about 8×10^{-6}.

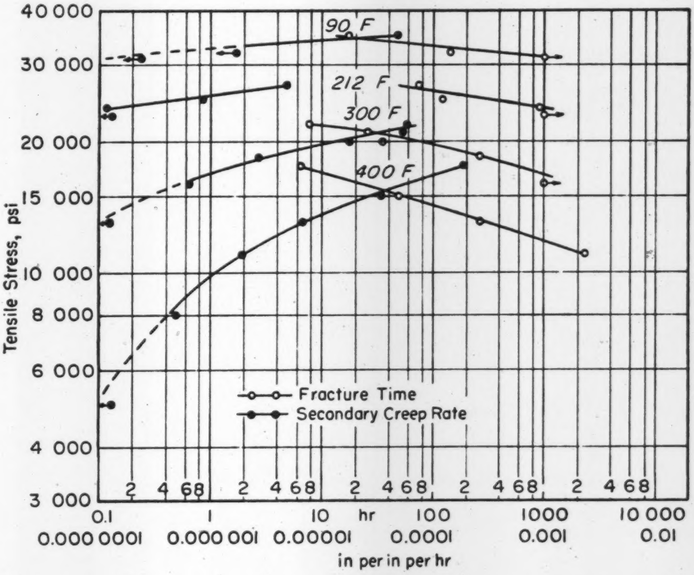


FIG. 7.—Secondary Creep Rate and Stress Rupture Characteristics for 319-T71 Sand-Cast Material.

EXPERIMENTAL RESULTS AND EVALUATION OF DATA

Creep curves of strain *versus* time were plotted for each creep test performed. A typical curve for a cast alloy is shown in Fig. 3. All of the significant data for creep were obtained from such curves. Tests wherein rupture had not occurred within 1000 hr were discontinued at that time.

The secondary creep rate, $\dot{\epsilon}$, also known as the minimum creep rate, was determined from the straight line portion of the creep curve. The creep intercept, ϵ_0, was obtained from an extension of the minimum creep rate line to zero time. At low stresses, the three stages of creep are extended over longer time intervals in contrast to higher stresses, so that in many low stress tests not only does the specimen not fail in 1000 hr but the rate of creep is still decreasing because the secondary stage of creep has not yet been reached. In such cases, it is only possible to state that the secondary creep rate is less than some estimated value approximating the minimum creep rate that was observed.

The total strain-time curves for the three sand-cast materials are recorded in

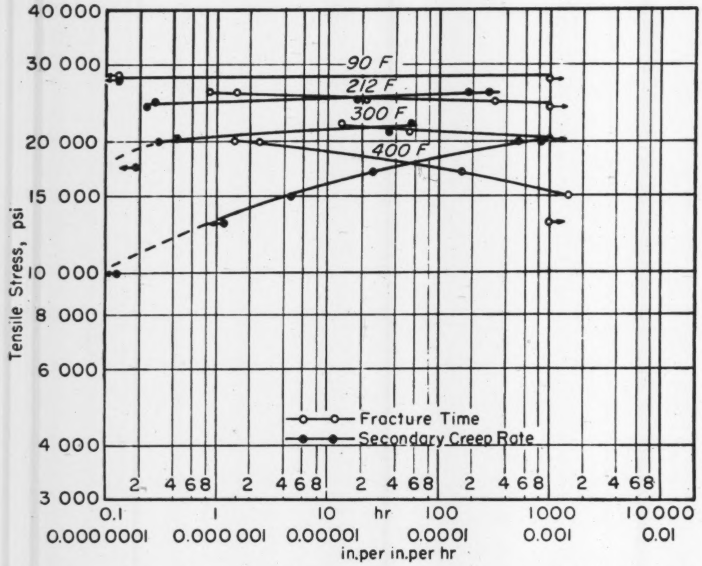


FIG. 8.—Secondary Creep Rate and Stress Rupture Characteristics for 319-F Sand-Cast Material.

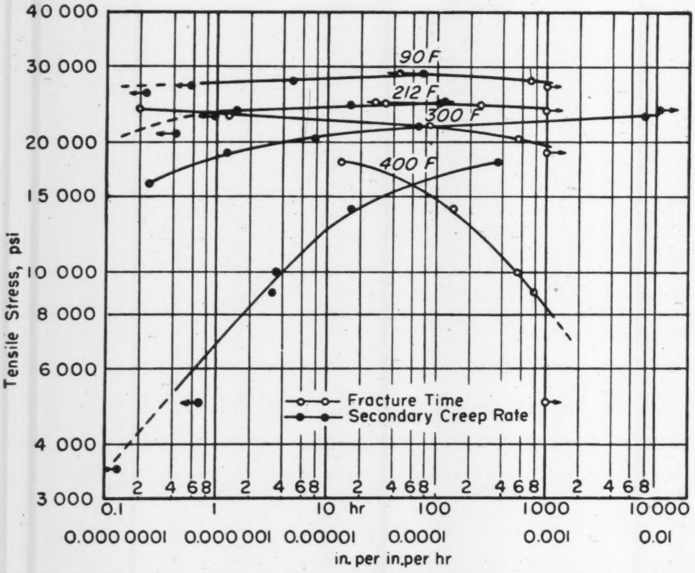


FIG. 9.—Secondary Creep Rate and Stress Rupture Characteristics for 356-T7 Sand-Cast Material.

Figs. 4 to 6. The solid points at the end of some of the curves refer to the time and strain at fracture for those cases where the specimens were stressed to failure. For purposes of design and discussion of relative creep resistance, stress *versus* secondary creep rate and stress *versus* fracture time curves are often used. These curves are included as Figs. 7, 8, and 9.

DISCUSSIONS OF RESULTS

The order of increasing tensile strengths listed in Table III does not agree with the order of increasing creep resistance even at test temperatures of 90 F. Table III shows that 319-T71 has the highest tensile and yield properties, 356-T7 is second, and 319-F has the lowest tensile and yield strengths. Reference to Figs. 7, 8 and 9 reveals the same order in creep resistance at 90 F for high stress or high secondary creep rate conditions, but at low stresses or low secondary creep rates the 319-F material becomes superior to the 356-T7 in its resistance to creep; the sand cast 319-T71 has the highest creep properties for all conditions of test at 90 F. At 400 F, however, the highest creep resistance was given by 319-F; 319-T71 gave intermediate creep properties; and 356-T7 gave the lowest creep resistance.

Several factors undoubtedly contribute to the observed inversion of the creep properties of the sand-cast 319-F material and the sand-cast, solution-heat-treated, quenched, overaged and stabilized 319-T71 material. Both the smaller grain size of the 319-T71 and the finer dispersion of the intermediate phases in the 319-T71 material contribute to its higher tensile properties and also its higher creep properties at 90 F. But such smaller grain sizes and finer dispersions usually yield a material that has less structural stability at higher temperatures; in consequence of this, higher creep rates are obtained than in more structurally stable states at elevated temperatures such as might occur in the as-cast 319-F material.

The stress rupture data recorded in Figs. 7, 8, and 9 also show the same general trends as the secondary creep rate data. At the low creep test temperature of 90 F, 319-T71 sand-cast material gave the highest resistance to rupture, whereas at the highest creep temperature of 400 F, 319-F material had the greatest resistance to rupture.

CONCLUSION

The creep and stress-rupture characteristics of aluminum sand-cast materials 319-T71, 319-F and 356-T7 were determined at test temperatures of 90, 212, 300, and 400 F.

The order of decreasing creep resistance at 90 F is 319-T71, 319-F, 356-T7, at 400 F, 319-F, 319-T71, 356-T7.

The inversion in the order of creep properties with increasing temperatures between the two tempers of sand-cast alloy 319 is probably ascribable to the difference in stability of the microstructure of the two materials as a function of temperature.

Acknowledgment:

This investigation was sponsored by the Aluminum Company of America. The authors wish to thank the Alcoa Laboratories for preparing the specimens, for the chemical analyses, and for the determination of the mechanical properties and microstructures. In particular they wish to thank R. L. Templin, F. M. Howell and F. G. Nelson for their helpful contributions to this program of research.

In addition the authors wish to thank M. Kawaguchi, M. Reporter and S. Lyman for their aid in executing the testing program. To Mrs. G. Pelatowski their sincerest appreciation is extended for the preparation of the graphs in this report.

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DISCUSSION

MR. F. M. HOWELL.[1]—In Figs. 7, 8, and 9 of this paper the authors have shown secondary creep rates and fracture times for three cast aluminum alloys at different stresses and temperatures. Mr. Dorn and his associates have made similar tests of some other sand cast aluminum alloys.[2] When data for eight of these alloys, including the three in the present paper, are considered, it is found that the secondary creep rates for all of them lie within relatively narrow bands, as shown in the upper parts of the accompanying Figs. 10, 11, and 12 for temperatures of 212, 300, and 400 F, respectively. The same is true of the fracture times shown in the lower parts of the same figures.

In Fig. 12 I have not drawn the left-hand end of the band low enough to include the authors' curve for 356-T7 because for a stress of 5000 psi they just determined that the secondary creep rate was not more than 0.00000008 in. per in. per hr. It might well be considerably less.

It is interesting to note that even with the wide range of compositions and thermal treatments the bands in general have a width of only about 5000 to 7000 psi.

MESSRS. O. D. SHERBY AND J. E. DORN (*authors*).—We thank Mr. Howell for illustrating the correlations between the creep resistances of various sand cast aluminum alloys.

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[1] Chief, Mechanical Testing Division, Aluminun Company of America, New Kensington, Pa.

[2] O. D. Sherby, T. E. Tietz, and J. E. Dorn, 'The Creep Properties of Some Forged and Cast Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 964 (1951) and "The Creep Properties of Sand Cast Aluminum Materials S5A, GS42A-F and C4A-T6," University of California Institute of Engineering Research (1951).

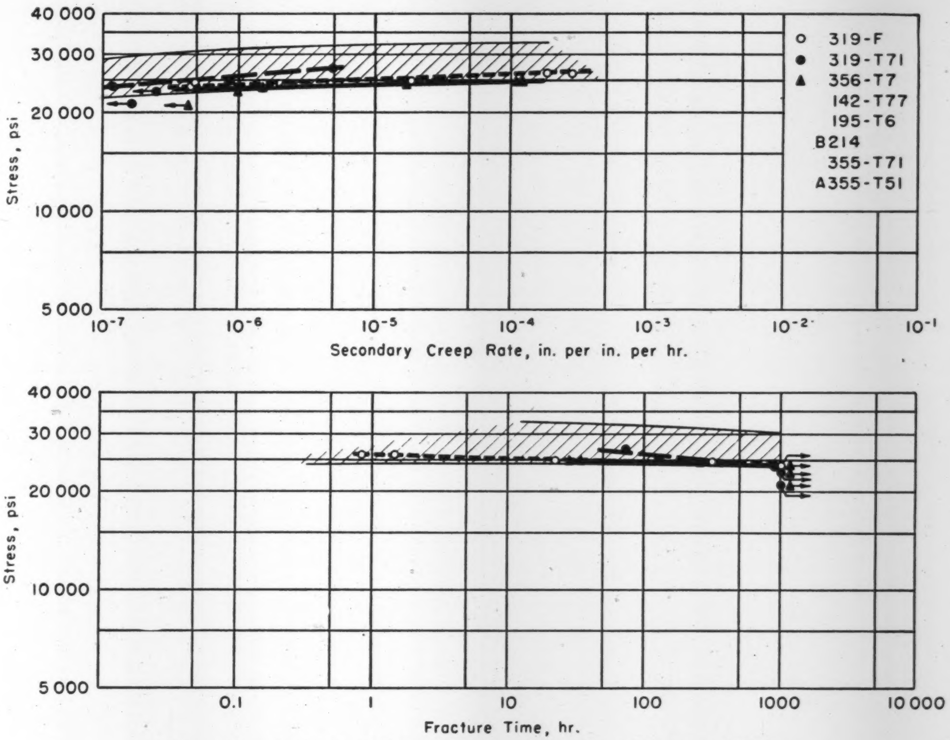

FIG. 10.—Secondary Creep Rates and Fracture Times at 212 F.

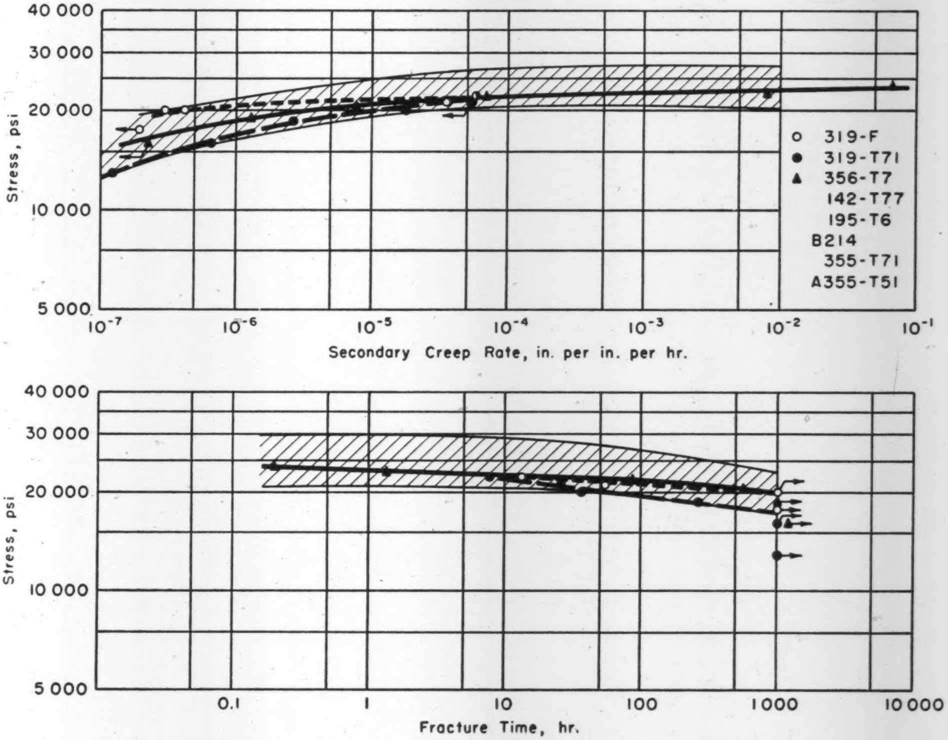

FIG. 11.—Secondary Creep Rates and Fracture Times at 300 F.

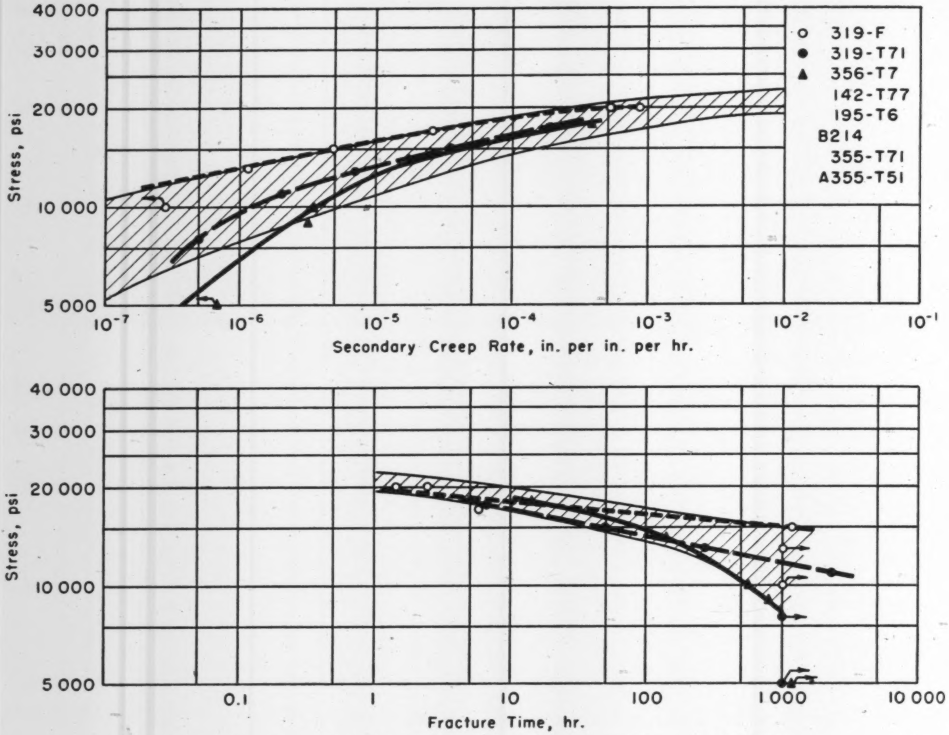

FIG. 12.—Secondary Creep Rates and Fracture Times at 400 F.

CREEP-TENSION RELATIONS AT LOW TEMPERATURES*

BY J. D. LUBAHN[1]

SYNOPSIS

The best previous notion of how to determine creep behavior from the results of tension tests was to cross-plot tension curves determined at various constant rates. This procedure will not yield the creep curves for metals like copper or 61S-T aluminum tested at room temperature because the stress-strain curves at different rates differ by less than the variations in deformation resistance among the specimens. A new procedure is suggested, based upon the relationship

$$\frac{\left(\frac{\partial \log S}{\partial \log \epsilon}\right)_{\dot{\epsilon}}}{\left(\frac{\partial \log S}{\partial \log \dot{\epsilon}}\right)_{\epsilon}} = -\left(\frac{\partial \log \dot{\epsilon}}{\partial \log \epsilon}\right)_{S},$$

a consequence of the hypothesis that mechanical behavior is independent of past history. If this equation were valid, the creep curves for various stresses could be calculated from a tension curve and from the rate sensitivity as determined by suddenly changing the rate in the tension test. Preliminary results encourage the idea that the above relation is applicable, but the results are too few as yet to be conclusive.

At temperatures where strain aging occurs, the above relation does not apply. However, it was found even for such conditions that

$$\left(\frac{\partial \log \dot{\epsilon}}{\partial \log \epsilon}\right)_{S}$$

is nearly constant for a given metal, and that the strain at a given rate and stress in creep is nearly the same as the strain at the same rate and stress in a tension test. With these facts, it is possible to construct the creep curve for any desired stress, using one measured creep curve and one measured tension curve.

Currently the most specific notions of how creep and tension curves might be related are based on the concept that plastic deformation behavior depends only on the amount of prior strain, not on the strain history, or manner in which that strain was introduced (1).[2] It follows directly from this concept that stress, plastic strain, strain rate, and temperature are related by an equation of the form

$$S = f(\epsilon, \dot{\epsilon}\ T) \ldots\ldots\ldots\ldots (1)$$

except, of course, when metallurgical

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] General Electric Research Laboratory, Schenectady, N. Y.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 932.

changes are accompanying the deformation (2). This equation has been called "the mechanical equation of state" (3), and specific functions *f* have been suggested (2, 4, 5).

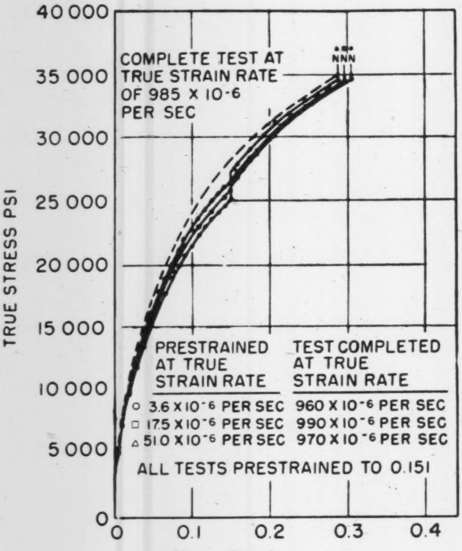

FIG. 1.—Effect of Strain Rate on the Work Hardening of 2S-O Aluminum Alloy at Liquid Nitrogen Temperature (78 K). From Tietz and Dorn (9).

A few early tests (3) indicated that the flow stress in tension was independent of the temperature of prior straining. However, more extensive later tests (6, 7, 8) show conclusively that the temperature of prior straining does influence the subsequent mechanical behavior.

There is little evidence to indicate whether the rate at which prior strain is introduced has a significant effect on the subsequent behavior. A group of tests on 2S aluminum at very low temperature (9) show only a small effect of prior strain rate on the subsequent flow stress (Fig. 1). Although the absolute effect is small, the effect is large relative to the effect of prior strain rate on the prior flow stress, or the "rate sensitivity" (Fig. 1). Thus, there is still the possibility that the rate history effects would be large at higher temperatures, where the rate sensitivity is large. The few existing tests at higher temperatures (3, 10) suggest that the effect of prior strain rate may be negligible.

There is some evidence for the existence of temporary rate history effects, or

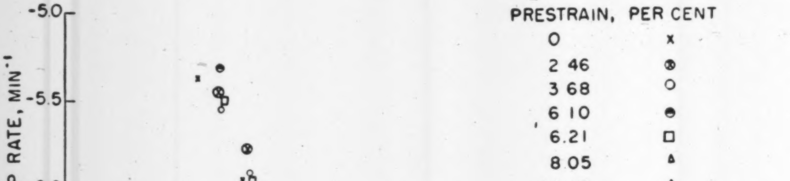

FIG. 2.—Effect of Rapid Prestrain on the Subsequent Creep Behavior of Polycrystalline Lead at Room Temperature (191.6 kg per sq mm). Derived from Data of Kennedy (13).

transients. Transients have been observed in lead following small changes in creep load, and in the aluminum alloy 61S-T following a sudden change in tension testing rate (11). However, the transients in 61S-T may be a strain-aging effect, since 61S-T strain ages at room temperature (12); there also may have been metallurgical changes involved in the experiments on lead. Furthermore, other experiments (13) on lead did not show rate history effects except at strains greater than 8 per cent (Fig. 2).

If the effects of prior strain rate were negligible, the strain reached in a creep test when the rate has diminished to a given value should be the same as that reached in a tension test at the same rate when the stress has risen to the creep stress, as illustrated in Fig. 3. Since a similar relationship was suggested by Orowan (14), as shown in Fig. 4, the relationship illustrated by Fig. 3 will be called "the modified Orowan relation." This relationship appears to be valid, although the best available data (15) scatter too much to provide a very good test (Fig. 5).

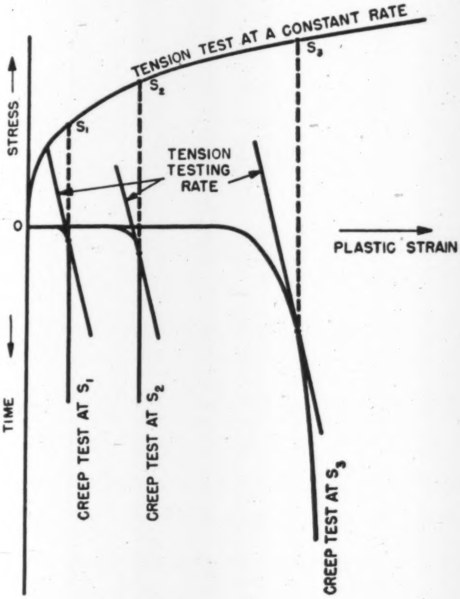

FIG. 3.—Schematic Diagram Illustrating a Relation Between Creep and Tension Behavior that Is One of the Consequences of the Mechanical Equation of State Concept.

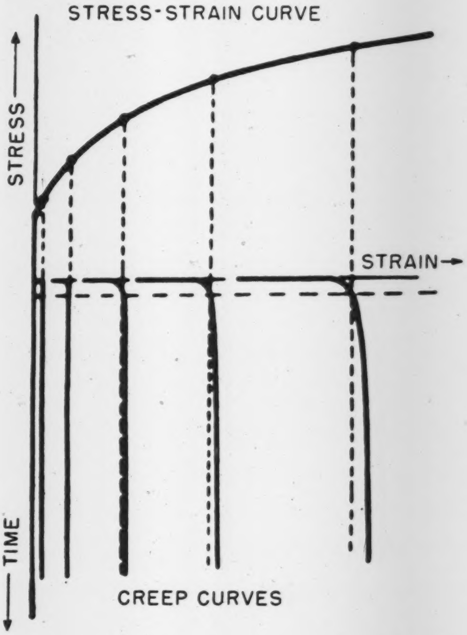

FIG. 4.—Schematic Diagram Illustrating the Relation Between Creep Tests and Tension Tests at Comparatively Low Temperatures (Orowan (14)).

Figure 3 indicates how tension curves could be constructed from measured creep curves if there were a mechanical equation of state. (See also Hollomon and Lubahn (2)) Similarly, rate *versus* strain curves for a constant stress could be obtained by cross-plotting tension curves at that stress; then the creep curves could be obtained by integrating curves of reciprocal rate *versus* strain, to obtain time (Fig. 6). Although the cross-plotting method is suitable in principle, it is inapplicable to data at comparatively low temperatures because of the low rate sensitivity. For most materials the rate sensitivity, defined by

$$n = \left(\frac{\partial \log S}{\partial \log \dot{\epsilon}}\right)_{\epsilon} \ldots\ldots\ldots\ldots (2)$$

is so small at low temperatures that the variation in flow stress for different specimens tested at the same rate is larger than the differences due to the largest rate changes that can be attained readily (15). For example, taking the rate sensitivity of 0.003 from Fig. 26, a flow stress difference as large as that for the two "identical" tests of Fig. 7 would require a rate difference of 10,000,000:1 in truly identical specimens. Similarly, if n were 0.003 and the available range of strain rates were 1000:1, the corresponding range of stress as determined from Eq 2 would be 2 per cent, which is a smaller change than typical variations in strength among several specimens. Under these conditions, a cross-plot at constant stress of tension curves at different rates would yield only a buckshot pattern, from which neither the variation of rate with strain nor the creep curve itself could be obtained.

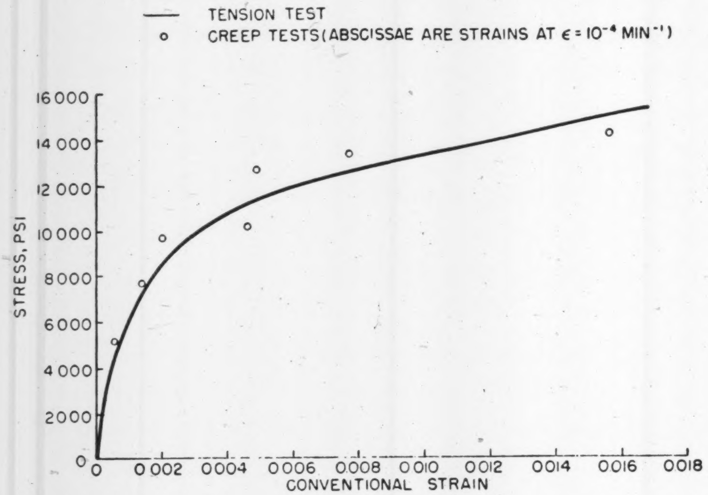

FIG. 5.—Room Temperature Stress-Strain Curve at Constant Strain Rate (0.003 per min) for OFHC Copper, as Compared with Creep Data Expressed as Creep Stress *versus* Strain at a Given Rate. From Lubahn (15).

From the foregoing discussion it is clear that the values of stress, strain, and strain rate are not profitable quantities to consider in attempting to derive low-temperature creep curves from tension behavior, because strain and stress vary so slowly with rate in low-temperature creep and tension tests. It is more profitable to recognize that the variations of strain and stress with rate are very small, and then to make use of a relationship between the two rates of variation. Such a relationship follows from mathematical considerations if the assumption is made that there is no effect of the rate of prior straining:

$$\left(\frac{\partial \log \dot{\epsilon}}{\partial \log \epsilon}\right)_S = -\frac{\left(\dfrac{\partial \log S}{\partial \log \epsilon}\right)_{\dot{\epsilon}}}{\left(\dfrac{\partial \log S}{\partial \log \dot{\epsilon}}\right)_{\epsilon}}\ldots\ldots(3)$$

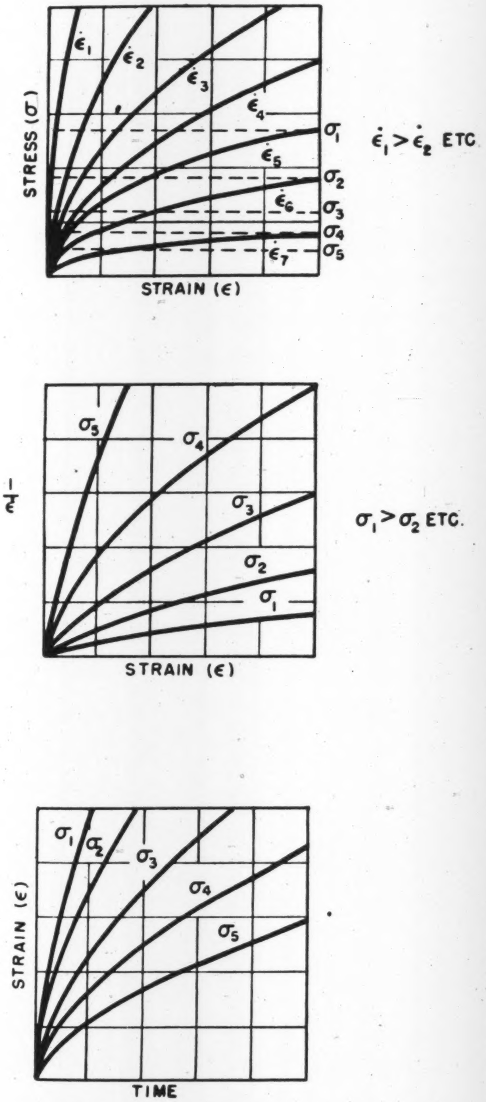

FIG. 6.—Derivation of Constant-Stress Creep Curves According to Concept of Mechanical Equation of State. From Hollomon and Lubahn (2).

The physical significance of this relation and the quantities involved is further discussed in Appendix I. Two of the quantities in Eq 3 are already familiar (2, 3, 16): the strain-hardening exponent

$$m = \left(\frac{\partial \log S}{\partial \log \epsilon}\right)_{\dot{\epsilon}}$$

and the rate sensitivity n as defined by Eq 2. The third quantity will be designated by p,

$$p = \left(\frac{\partial \log \dot{\epsilon}}{\partial \log \epsilon}\right)_S\ldots\ldots\ldots\ldots(4)$$

With this nomenclature Eq 3 becomes simply

$$p = -\frac{m}{n}\ldots\ldots\ldots\ldots\ldots(5)$$

The quantity p merits a few words because of its convenience in expressing low-temperature creep behavior, in addition to its appearance in Eq 5. p is a measure of how rapidly the creep rate decreases with strain in a constant-stress test. For viscous behavior, where the creep rate is proportional to stress and independent of strain, the creep rate does not change with strain and $p = 0$. This behavior corresponds to what has been called viscous creep (17)—a behavior that has been assumed to prevail during the "secondary creep" of constant load tests, where the decreasing rate due to strain hardening is temporarily offset by the effects of metallurgical softening or by the effects of increasing stress accompanying a decreasing cross-section. Actually, viscous creep is only approached, but not reached (15, 18), except in certain special cases (19) where a balance between strain hardening and recovery may be reached. For a metal that undergoes sudden plastic deformation upon the application of a constant stress, but

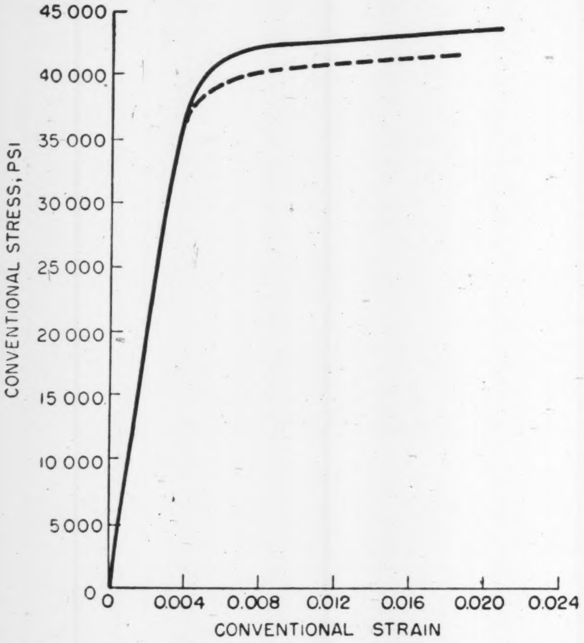

FIG. 7.—Results of Two Identical Tension Tests on 61S-T at Room Temperature. Strain rate: 10^{-4} per min.

does not creep (in the sense that no gradual deformation subsequently occurs), $p = -\infty$. The strain rate decreases from ∞ to zero during an infinitesimal increment of strain. When $p = -\infty$ we say that the metal does not creep, whereas the essence of creep behavior is expressed by $p = 0$. Thus, the quantity p can be envisioned as a measure of "creepability," or tendency to creep. It is convenient for describing creep behavior because it is comparatively insensitive to stress, strain, or strain rate, as will be shown later. In this respect, p is similar to m and n, which also vary slowly with stress, strain, or strain rate. Furthermore, it appears that p is important because it is one of the quantities that will be related to m and n, even though it is found that there is an effect of rate history and that Eq 5 is incorrect. The nature of possible deviations from Eq 5 is more readily apparent from the physical interpretation of Eq 5 given in Appendix I.

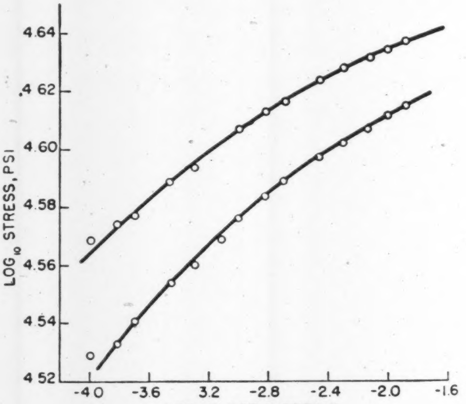

FIG. 8.—Stress-Strain Curves of Fig. 7 on Logarithmic Coordinates.

The ideas discussed above will be helpful in understanding the test results described below for the aluminum alloy 61S-T and for OFHC copper.

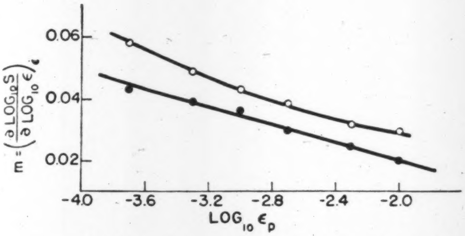

FIG. 9.—Variation of Strain-Hardening Exponent (*m*) with Strain for 61S-T at Room Temperature.

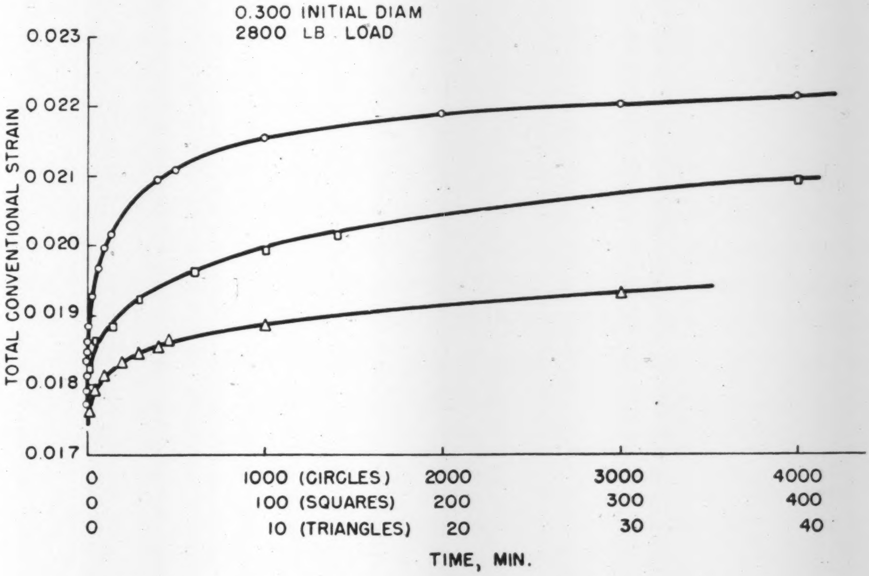

FIG. 10.—Typical Creep Curve for 61S-T at Room Temperature.

MATERIALS AND PROCEDURE

Room-temperature creep tests and tension tests were made on 61S-T (an aged aluminum alloy) and OFHC copper. Room temperature, rather than some higher temperature, was selected in order to minimize the possibility of metallurgical changes.

Most of the 61S-T specimens were tested in the as-received condition (solution-treated at 960 to 980 F, aged 8 hr at 345 to 355 F) after a considerable interval of time following receipt of the material. Thus, there was a long period (perhaps six months) of aging at room temperature after the elevated-temperature aging. Specimens Nos. 193 and 194, on the other hand, were reheat-treated by solution treating at 980 F and aging 5 hr at 355 F and then were tested within a few days after the elevated-temperature aging.

A few tests were made on the OFHC copper in the condition in which it was received—commercially cold drawn. Most of the tests on the copper were made on specimens that had been annealed at 600 C for 1 hr.

With the exception of 61S-T tests Nos. 193 and 194, it seems likely that none of the tests was affected by metallurgical changes such as age hardening and grain growth that do not require strain to proceed. The specimens had been either (*a*) previously heat treated at a higher temperature than the testing temperature or (*b*) allowed to remain at room temperature for a long time preceding the test.

Strain aging and recovery experiments on OFHC copper (12) indicate that neither strain aging nor recovery occurs in OFHC copper at room temperature. However, there is now definite evidence that strain aging may have occurred in the tests on 61S-T. This material exhibits transient effects, discontinuous yielding phenomena, and a minimum in rate sensitivity at room temperature (20) that may be due to strain aging (12).

The testing techniques were similar to those used earlier (20). However, one additional refinement of the creep-testing technique was developed in order to measure as much as possible of the early part of the creep curve, where the creep rate is very high. The chart drum of the recorder rotates at a maximum speed corresponding to a strain rate of 0.015 per min. If the recorder were allowed to read correctly before applying the load, a long time would be required for it to read correctly again after loading, because of the large initial strain. For example, it would take 40 sec to reach a total strain of 0.010, if that were the strain at which the rate had decreased to 0.015 per min. To avoid missing the first part of the creep curve (the first 40 sec in the above example), the recorder was initially set out of balance at an estimated position such that it would be in balance when the creep rate had decreased to 0.015 per min. The motor switch was not turned on until an instant after the load was applied. Depending on whether the estimated strain was larger or smaller than that actually reached in the test at a rate of 0.015 per min, the recorder had to back up (for example, see Fig. 25) or go forward to reach the correct strain value, but only by a comparatively small amount. By this means, strain rates as high as 0.007 per min, or half the maximum speed of the recorder, were measured (see Fig. 15).

RESULTS OF TESTS ON 61S-T

The stress-strain curves for two tension tests on 61S-T at 10^{-4} per min are shown in Fig. 7. For the purpose of determining the quantity m in Eq 5, the tension data have been replotted on log-log paper in Fig. 8. It is evident that the slope m is not independent of strain. The possibility that $\log S$ *versus* $\log \epsilon$ is always linear was suggested earlier (21) on the basis of numerous tests; but many exceptions have been noted subsequently (see Jackson (16), for example). The variation of m with strain for the data of Fig. 8 is approximately 2:1 within the range of 100:1 in strain that was investigated. This is shown also in Fig. 9, which gives the slopes of the curves in Fig. 8.

A constant-load strain-time curve for 61S-T is illustrated in Fig. 10. The slope changes so much that several magnifications in the time scale are required to show completely the range of strain rates involved during one test.

Strain-time curves for all the creep tests on 61S-T are shown in Figs. 11 and 12. A preliminary examination reveals that all of the curves level off rather abruptly. According to the modified Orowan relation pictured in Fig. 3, the creep curves in Figs. 11 and 12 should "level off" at strains that bear the same functional relation to the creep stresses[3]

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[3] Actually, all but one of the creep tests were constant-load tests. However, for the small strains involved here, creep curves for constant stress and constant load have the same shape (within the limit of the scattering). This fact is illustrated by one test (No. 269) at constant stress, made by the method of Fullman, Carreker, and Fisher (22), which fits nicely into the family of constant-load curves according to any representation of the data (see Figs. 11, 12, 15, and 16). The results will be analyzed as though they were all from constant stress tests.

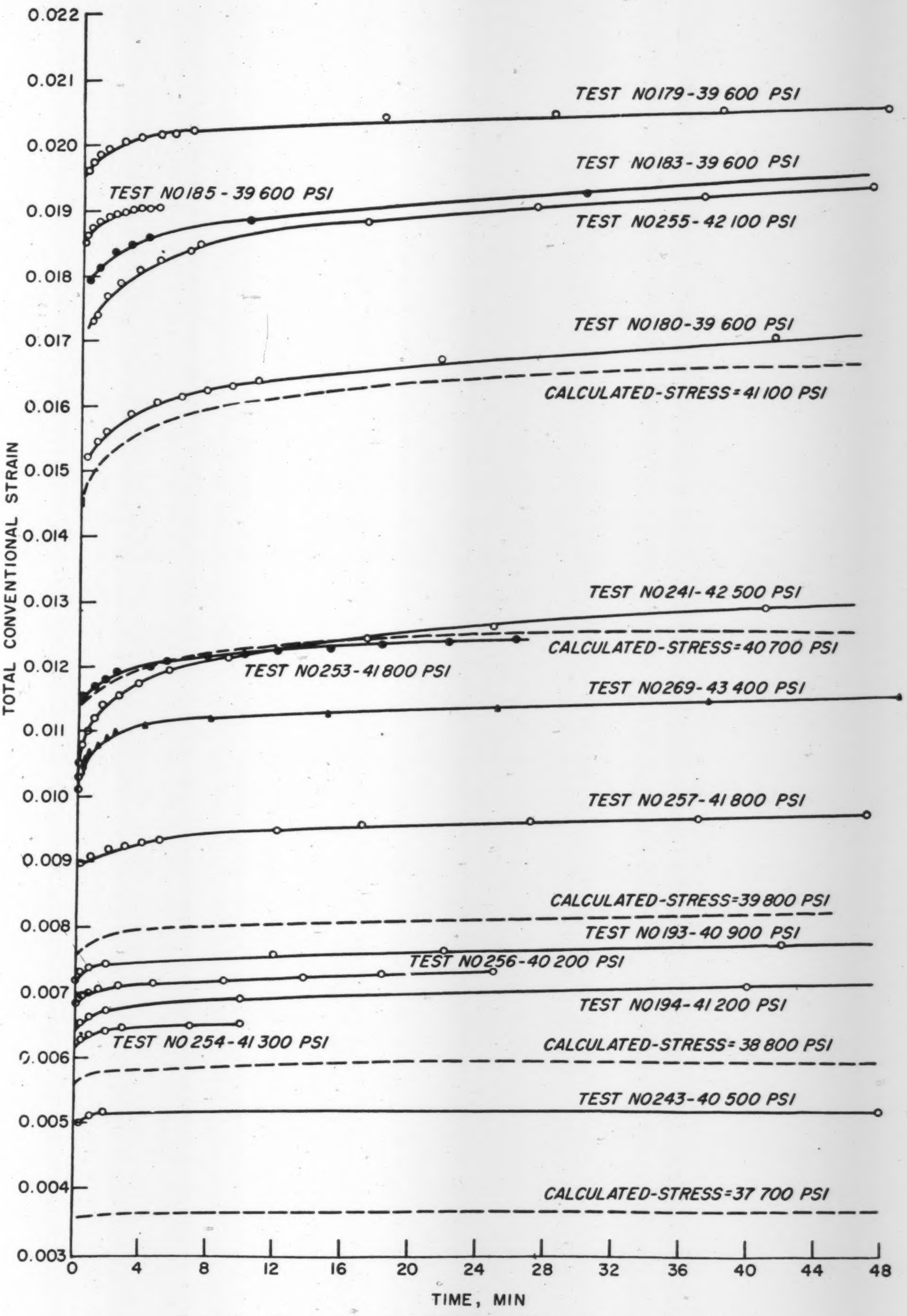

FIG. 11.—Creep Curves for 61S-T at Room Temperature.

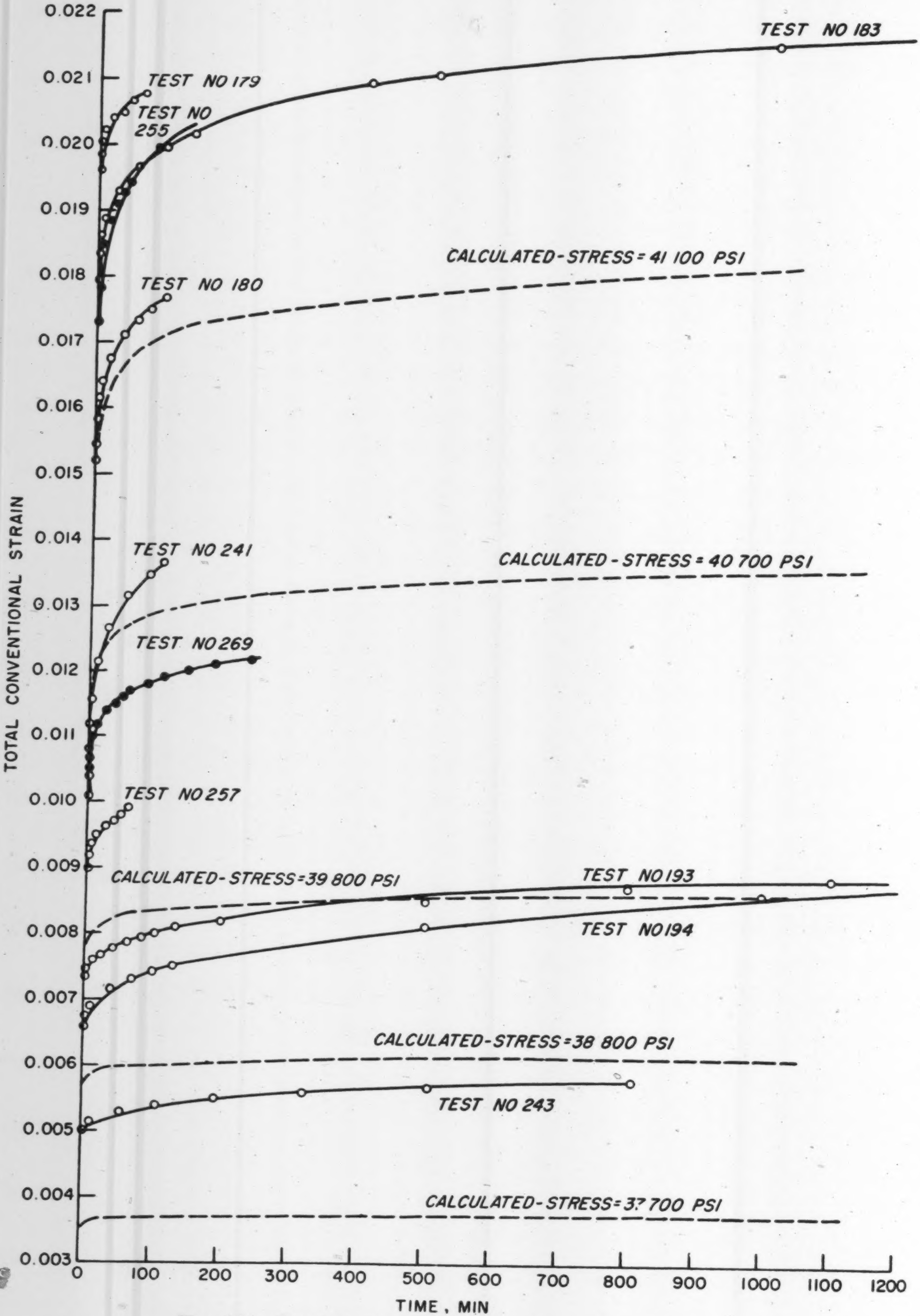

FIG. 12.—Creep Curves for 61S-T at Room Temperature.

as do stress and strain in a tension test ("leveling off" in this case meaning that the creep rate has decreased to the tension-testing rate). A consistent relation between creep stress and "leveling-off" strain is not readily apparent from Figs. 11 and 12—a fact that is not surprising when one considers the scattering of the data expressed as creep stress *versus* "leveling-off" strain and plotted in Fig. 13. The whole range of stress covered by the experiments is small, because of the small rate of strain hardening of the metal; and the scattering is so great by comparison that it is not possible to say even whether the trend line should have a positive or negative slope. Yet the absolute value of the scattering is no larger than that encountered in most metals; disregarding the four early tests at the lowest stress, which may have come from a different batch of material, there is a scattering in stress of only ±2 per cent about a trend line parallel to, and lying between, the two tension-test curves.

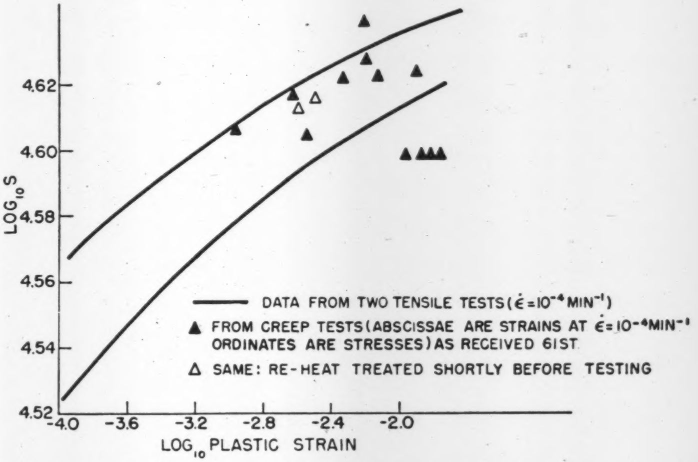

FIG. 13.—Comparison of Stress-Strain Behavior Measured in Tension Tests with Creep Data Expressed as Creep Stress *versus* "Leveling-Off" Strain (61S-T).

To summarize: the creep and tension data on 61S-T assembled in Fig. 13 are not sufficient to show whether or not the modified Orowan relation shown in Fig. 3 is valid. The validity of this relation is shown much more convincingly by the earlier data on copper where the range of stresses covered by the tests (see Fig. 5) is so much larger than that of the data in Fig. 13 that a particular trend can be established, even though the absolute scattering is no less.

Further examination of Figs. 11 and 12 reveals that the higher curves do not level off as abruptly as the lower ones. As the "leveling-off" strain increases, there is a gradual and continuous decrease in curvature in the sharply-curved region. When the strain reached in the creep test is small, the creep rate decreases very abruptly from a very large strain rate (too rapid for the recorder to follow) to a very small strain rate (too slow to measure with the sensitivity and stability of the available strain gage). The strain appearing at a measurable rate was almost too small to measure for the test corresponding to the lowest

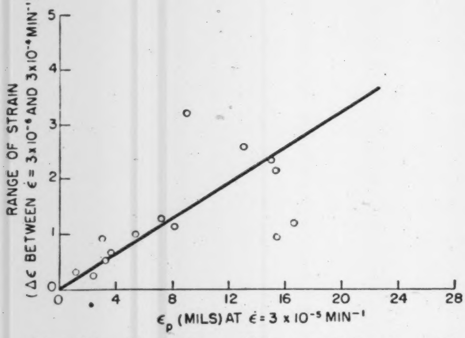

FIG. 14.—Variation of Range of Strain with Leveling-Off Strain for Creep of 61S-T.

curve in Fig. 11. The "strain appearing at a measurable rate" is a quantity that depends on the creep rates bounding the strain interval, and thus on the characteristics of the measuring equipment; but since it is a convenient quantity for comparing the relative creep behaviors of specimens tested with the same equipment, it will be designated as "the range of creep strain."

Regarding the progressive change in shape with position for the curves of Figs. 11 and 12, the shape change can be described in terms of the "range of strain" just defined; the range of strain increases with the leveling-off strain. The trend is definite: that is, the scattering is smaller than the magnitude of the effect. The nature of the trend is more clearly revealed in Fig. 14 which shows the amount of strain appearing between 3×10^{-4} per min and 3×10^{-6} per min plotted *versus* the strain at 3×10^{-5} per min. The definiteness of the trend in Fig. 14 is rather surprising, considering the lack of trend of creep stress *versus* leveling-off strain shown in Fig. 13.

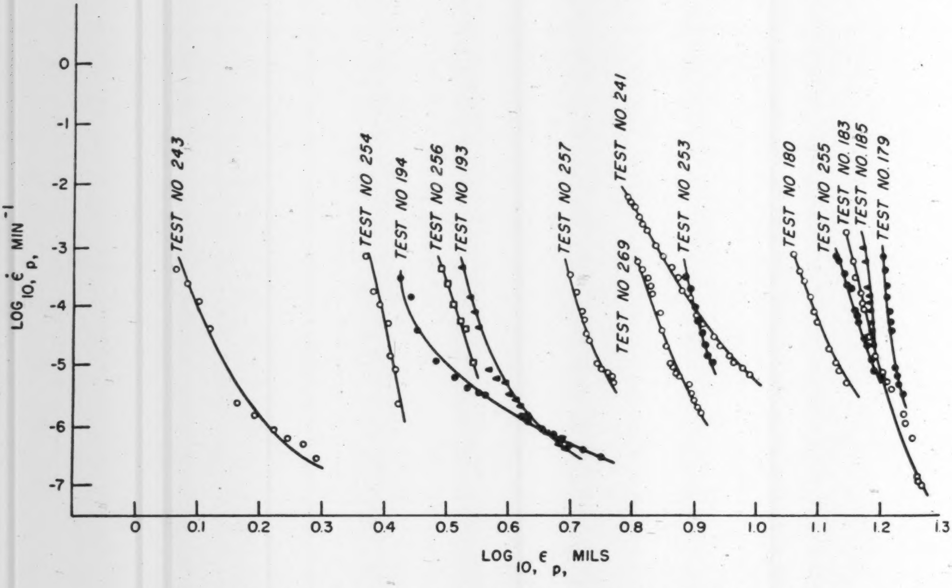

FIG. 15.—Room-Temperature Creep Curves of 61S-T at Various Loads.

In Fig. 15, the data of Figs. 11 and 12 have been replotted as log rate *versus* log plastic strain. The elastic strain to be subtracted from the total strain to yield plastic strain was obtained by dividing the stress by a modulus value of 10,500,000 psi. With this representation, the creep curves are usually nearly linear (except for the special cases of tests Nos. 193 and 194), with some tendency to show upward concavity. The nearly linear behavior in the representation in Fig. 15 indicates that the creep rate is finite for a considerable range of strain both before the beginning of the measurements and at times longer than the last measurement. This conclusion is in sharp contrast to the impression one might acquire from Figs. 11 and 12 that the initial strain is instantaneous and that creep ceases upon reaching a sufficient strain. The only reason that the behavior seems this way is that the rate is too large in the early part of the test for the recorder to follow, and too small in the later part of the test to yield a sensible lengthening in a time that is reasonable to wait.

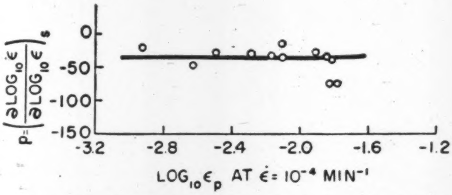

FIG. 16.—Variation of p with Strain for 61S-T at Room Temperature.

It is also evident from Fig. 15 that the average slopes of the log rate *versus* log strain curves are all about the same; that is, p is about the same for all the tests. This fact is shown more clearly in Fig. 16, in which p is plotted against the strain at $\dot{\epsilon} = 10^{-4}$ per min. Referring to the definition of p in Eq 4, it will be clear that a constant value of p among several tests implies a constant (Δ log ϵ) for a given change in rate, or a proportionality between range of strain and leveling-off strain, remembering that

$$\Delta \log \epsilon \sim \frac{\Delta \epsilon}{\epsilon} \ldots\ldots\ldots\ldots (6)$$

for the small increments involved here. The proportionality between range of strain and leveling-off strain has already been suggested by the trend line in Fig. 14.

The constancy of p during any single test and from one test to another may have fundamental significance with regard to the validity of the relation

$$p = -\frac{m}{n}.$$

The quantity m varies but little during one tension test or from one test to another at different rates; likewise, n is always nearly the same, regardless of the strain at which the change in rate is made or the value of rate before or after the change. If m and n are insensitive to testing conditions, then one would expect p to be insensitive to the testing conditions also, if

$$p = -\frac{m}{n}.$$

Of course, the relative constancy of p, m, and n for a given metal at a given temperature requires only proportionality, not equality, of p and

$$\left(-\frac{m}{n}\right).$$

The fact that p is nearly independent of creep stress and nearly constant during any one creep test is consistent with earlier observations (24, 25) that plastic strain is linear with time in log-log coordinates. This linearity means that the empirical equation for creep curves is of the form

$$\epsilon_p = Kt^a$$

which is of the same form as Eq 10 if

$$a = \frac{1}{1 - p}.$$

Thus, if log ϵ_p *versus* log t plots for different stresses are straight and parallel, that is, if a is constant, then p is also independent of creep stress and constant during any one creep test. This fact is illustrated in Fig. 17, which shows that test No. 255 yields a straight line whether plotted as log ϵ_p *versus* log t or as log $\dot{\epsilon}$ *versus* log ϵ_p. The value of p of -27.6 requires a value of 0.0350 for a according to the above equation, and this a value is close to the measured slope of 0.0353 in Fig. 17.

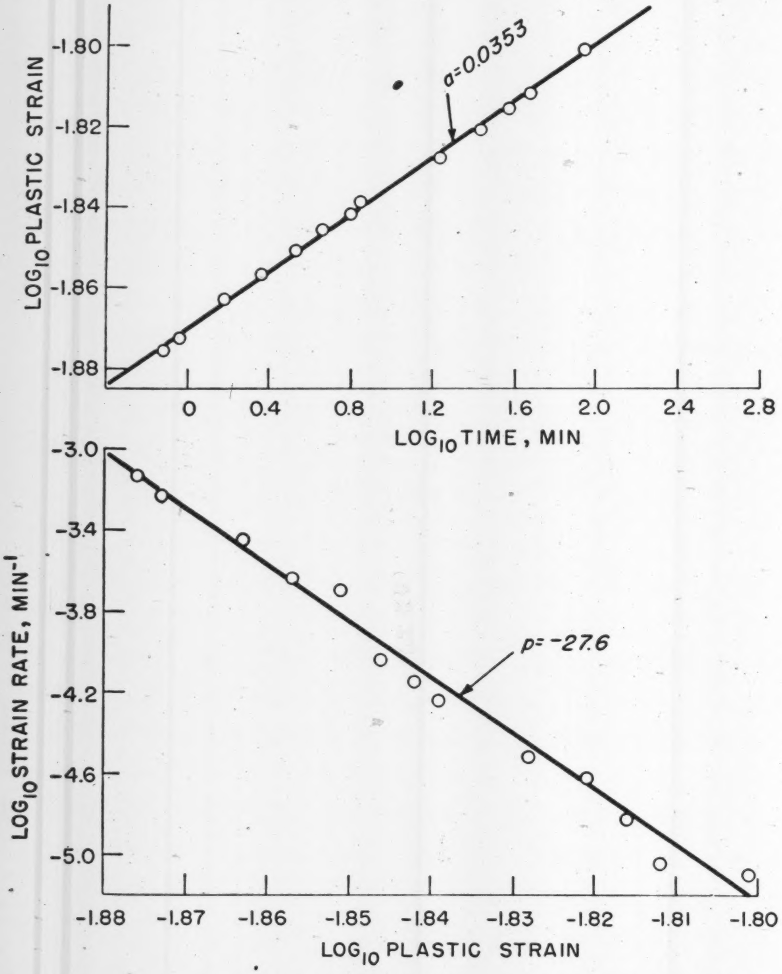

FIG. 17.—Creep Data for 61S-T Tested at Room Temperature and at a Stress of 42,100 psi (Test No. 255).

Although a few tests yielded straight log $\dot{\epsilon}$-log ϵ_p curves (and thus also straight log ϵ_p-log t curves), most of the log $\dot{\epsilon}$-log ϵ_p curves were slightly curved (see Fig. 15) and the log ϵ_p-log t curves were correspondingly non-linear, as shown in Fig. 18. Such curvature was sometimes observed by Sturm, *et al* (24); and although Davis (25) obtained straight lines when he took the zero of plastic strain at the end of an 8 per cent prestretch, the lines would have been curved if the annealed condition had been taken as the zero of plastic strain (see Fig. 19).

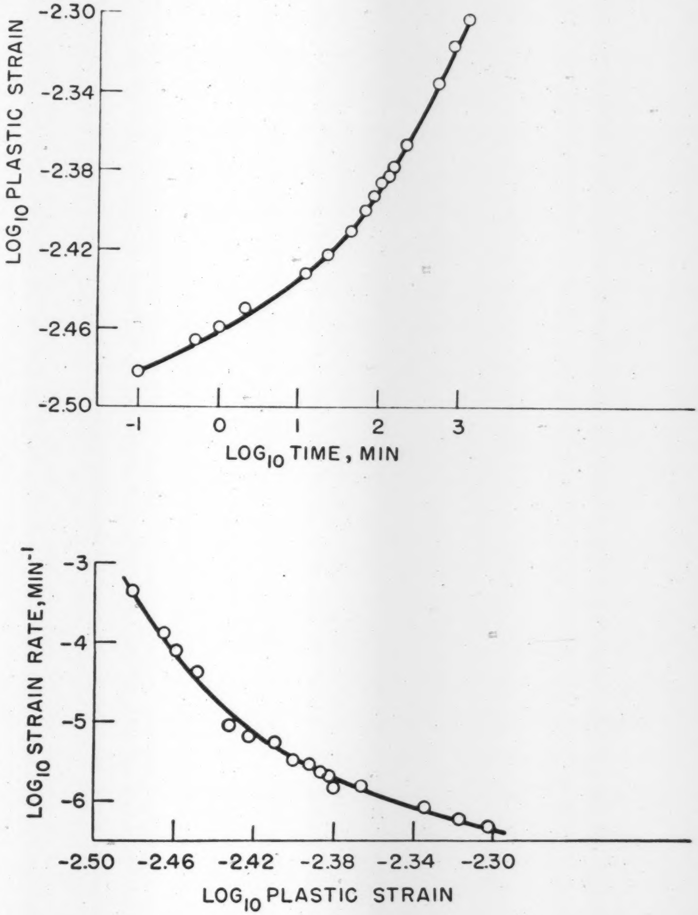

FIG. 18.—Creep Data for 61S-T Tested at Room Temperature and at a Stress of 40,900 psi (Test No. 193).

If the points in Fig. 19 are faired with straight lines, the slopes ("*a*" values) range between 0.0001 and 0.0004, which correspond to values of *p* ranging from -2500 to $-10{,}000$ according to the above equation. These *p* values are about ten times the value from Fig. 24 for annealed copper. Sturm (24), on the other hand, obtained $a = 0.2$ for "soft copper," which corresponds to $p = -4$ according to the above equation. This *p* value is 100 times smaller than the value from Fig. 24 for annealed copper. These discrepancies between the values of *p* found by several investigators might correspond to real differences in mechanical behavior among several grades of copper. There is also the possibility that Sturm's method of determining the elastic strain (to be subtracted from the measured total strain to obtain plastic strain) yields incorrect values when a large fraction of the plastic strain occurs in the first few seconds (or while the load is being applied). For example, applying his method to the data of test No. 193 (see Figs. 11 and 12) yielded an "elastic" strain of 0.0073, whereas a modulus value of 10,500,000 psi and creep stress of 40,900 psi would indicate an elastic strain of 0.0039. A straight log ϵ_p-log t curve is obtained using 0.0073 for the elastic strain, but the log ϵ_p-log t line is curved if the elastic strain is taken as 0.0039.

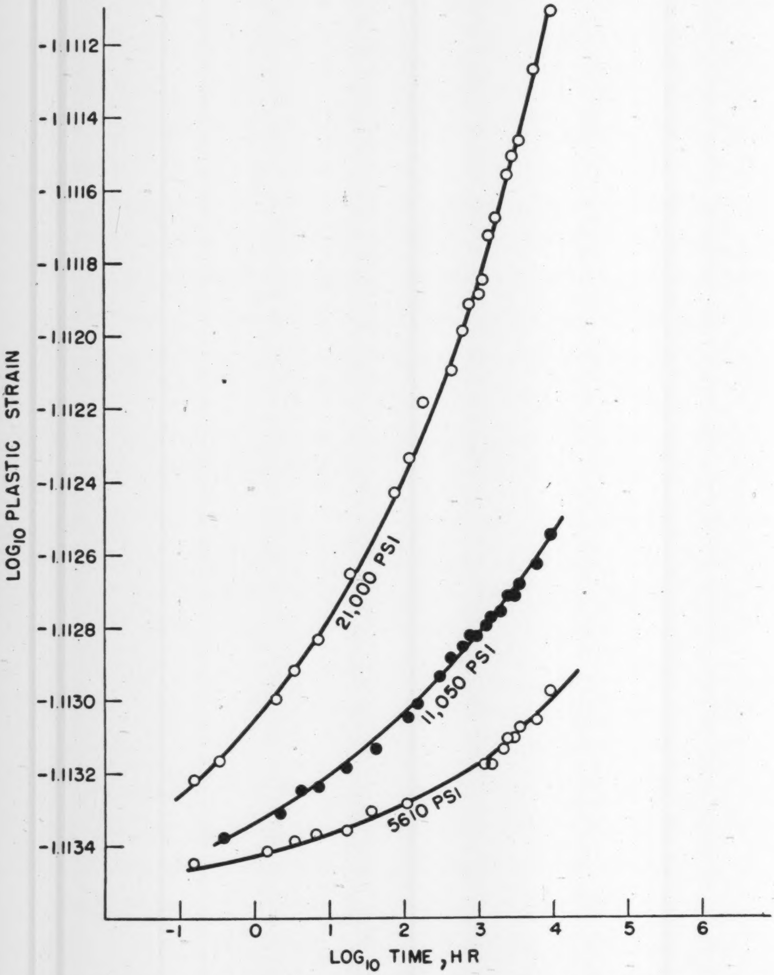

FIG. 19.—Creep Curves for OFHC Copper Tested at Room Temperature. Plotted Strain Includes 8 per cent Prestrain. From Data of Davis (25).

In addition to the fundamental import of the constancy of p, there is also practical value attached to this fact. If p were the same for creep tests at different loads, all the creep curves could be calculated from one measured curve, as shown in Appendix II. (In order to determine the stress to be associated with each calculated creep curve, it is necessary to utilize the modified Orowan relation.) The dashed curves in Figs. 11

and 12 were calculated from an average value of p of -38 (see Fig. 16) and the upper tension curve of Fig. 7, using the method of Appendix II. The variation of shape with position is very similar to that observed experimentally.

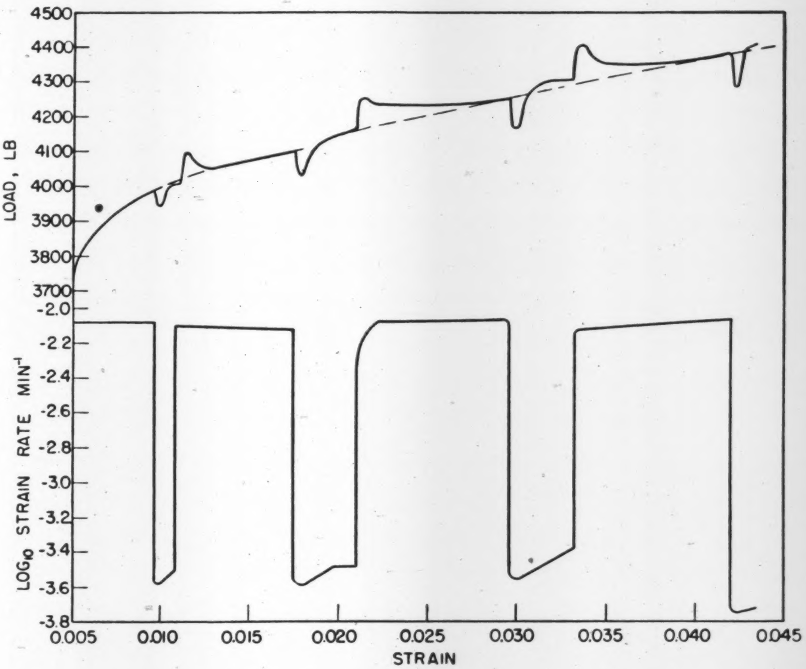

FIG. 20.—Transient Effects in a Tension Test on 61S-T at Room Temperature.

Considering that p is about -40 (Fig. 16) and m is about 0.04 (Fig. 9) for 61S-T, n should be about 0.001 if

$$p = -\frac{m}{n}.$$

Values of n obtained (20) from the change in load caused by a change in rate in a tension test are uncertain because of pronounced transient effects, as shown in Fig. 20. Apparently n is approximately zero at room temperature, and changes rapidly with temperature from positive above room temperature to negative below room temperature (20). For this kind of variation of n with temperature, the relation

$$p = -\frac{m}{n}$$

would require that p also change sign near room temperature, with creep rate increasing rapidly for tests slightly below room temperature and creep rate decreasing rapidly for tests slightly above room temperature. It does not seem likely that such a discontinuity with temperature exists in the creep behavior. It appears more likely that

$$p = -\frac{m}{n}$$

does not apply at all to the behavior of 61S-T at room temperature. Such inapplicability seems reasonable in view of the fact (12) that 61S-T strain ages in the neighborhood of room temperature and that strain aging causes an abnormally small rate sensitivity as measured in a tension test (12).

Direct evidences of the strain aging process are not readily apparent in the creep behavior of 61S-T at room temperature. However, it was observed that in tests Nos. 193 and 194, which were tested soon after heat treating, there was an abnormally high curvature in the log $\dot{\epsilon}$-log ϵ graph (Fig. 15). It was observed earlier (20) that other strain aging effects were more pronounced in recently aged 61S-T, and the higher curvature for tests Nos. 193 and 194 in Fig. 15 may be another example of the effects of the strain aging process.

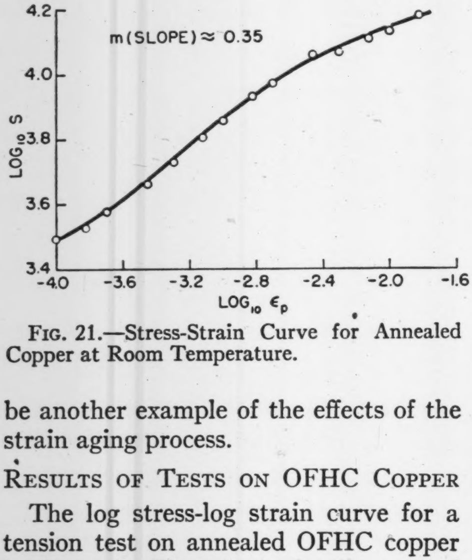

FIG. 21.—Stress-Strain Curve for Annealed Copper at Room Temperature.

RESULTS OF TESTS ON OFHC COPPER

The log stress-log strain curve for a tension test on annealed OFHC copper is shown in Fig. 21. As in the case of 61S-T (Fig. 8), the graph is not linear; there is a variation in slope *m* of about 2:1. The average slope of 0.35 is about ten times that for 61S-T.

Figure 22 shows a strain-time curve for annealed OFHC copper. The creep curve for copper levels off much more abruptly than the curve for 61S-T that reaches essentially the same strain. This fact is illustrated by the comparison in Fig. 23, which shows that the copper exhibits the same decrease in rate as 61S-T in an interval of strain that is only one-tenth as long. In other words, at the same strain level the creep rate decreases with strain ten times as rapidly for copper as for 61S-T. In terms of the range of strain, the copper exhibits one-tenth the range of strain that 61S-T does. The relative creep behaviors of copper and 61S-T can also be expressed in terms of p, which by definition is inversely proportional to the range of strain ($\Delta\epsilon$) for a given strain level (ϵ_0) and a particular range of rates ($\Delta \log \dot{\epsilon})_0$; thus:

$$p = \frac{(\Delta \log \dot{\epsilon})_0}{\left(\frac{\Delta\epsilon}{\epsilon_0}\right)} \qquad \text{(7)}$$

for the small increments involved here. Figure 24 shows that p is about -420 for the test on annealed copper shown in Fig. 22. This value is about ten times the average value of p for 61S-T (Fig. 16).

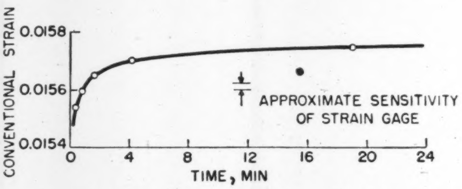

FIG. 22.—Creep Curve for Annealed Copper at Room Temperature; 14,100 psi Nominal Stress.

As noted earlier, the value of p was constant for the different tests on 61S-T, so that the range of strain was proportional to the leveling-off strain. If p also were the same for tests on copper at different loads, one would expect the range of strain to be unmeasureable at the smaller values of leveling-off strain, for even in the case of the largest strain attainable without exceeding the travel of the strain gage, the range of strain was not many times the sensitivity (Fig.

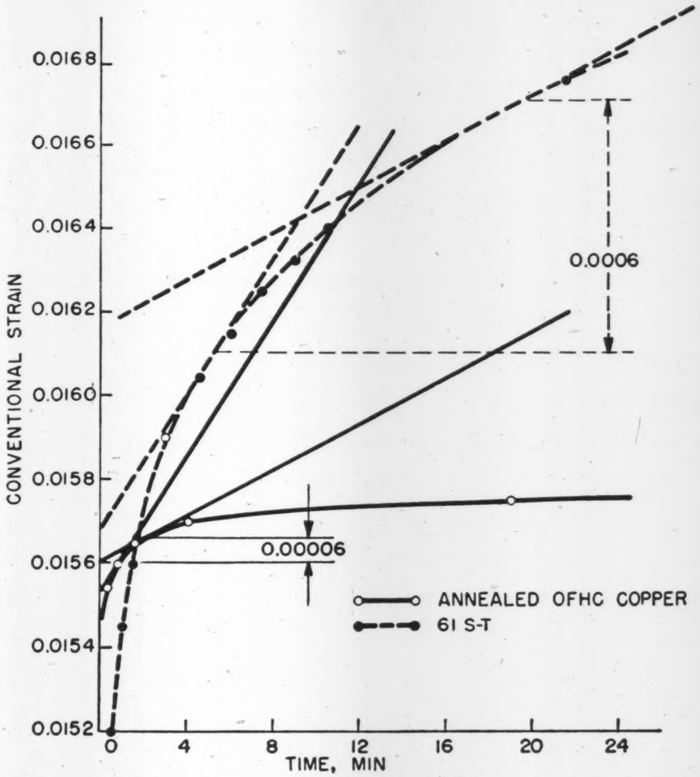

FIG. 23.—Comparison of Room-Temperature Creep Behaviors of 61S-T and Annealed Copper.

22). Table I lists the values of range of strain expected from the leveling-off strains shown, assuming that p is the same for all the tests as in test No. 249. These values are all very small, as expected, many being smaller than the sensitivity of the gage. The table also shows the measured[4] range of strain, which was too small to be detected in all but two of the tests. Figure 25 shows the creep curve for one of the tests where the range of strain was barely measurable.

From the value $p = -420$ (Fig. 24) for annealed copper and the approximate value of m of 0.35 (Fig. 21), Eq 5 yields a value of n of about 0.001. From tension tests where one measures the change in

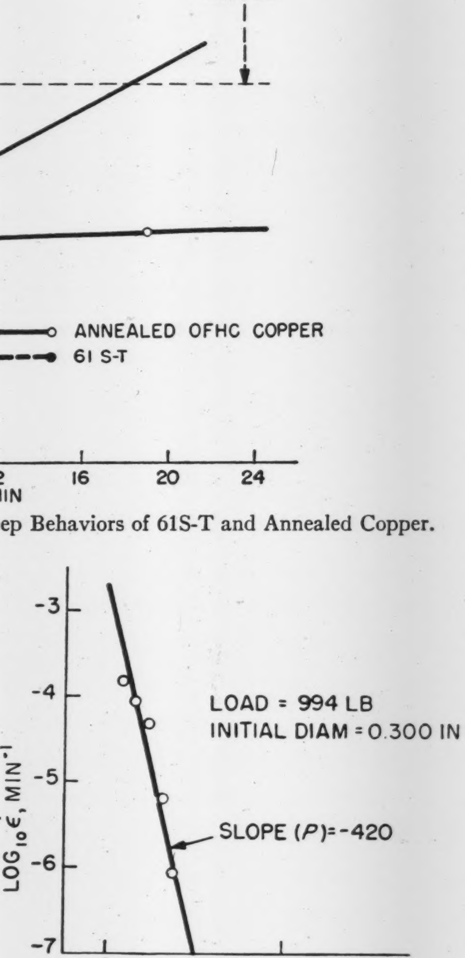

FIG. 24.—Creep Curve for Annealed Copper at Room Temperature.

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[4] The measured values of range of strain are between poorly defined limits of rate, depending among other things upon the time required for the recorder to reach the leveling-off strain from its initial position, the sensitivity and stability of the strain gage, and the (arbitrary) duration of the test. Figure 25 illustrates the uncertainties of the rate limits.

TABLE I.—RANGE OF STRAIN.

Test	Nominal Stress, psi	ϵ at $\dot{\epsilon} = 10^{-4}$ per min, mils per in.	Measured Range of Strain ($\Delta\epsilon$ at a Measurable rate) (mils per in.)	Calculated Range of Strain, (mils per in.)
No. 246.....	12 600	4.11	0	0.06
No. 247.....	5 000	0.24	0	0.00
No. 248.....	10 000	3.97	0	0.05
No. 249.....	14 100	14.75	0.20	0.20 assumed
No. 250.....	7 500	0.93	0	0.01
No. 251.....	9 500	1.26	0.05	0.02
No. 252.....	13 300	6.80	0.05	0.09

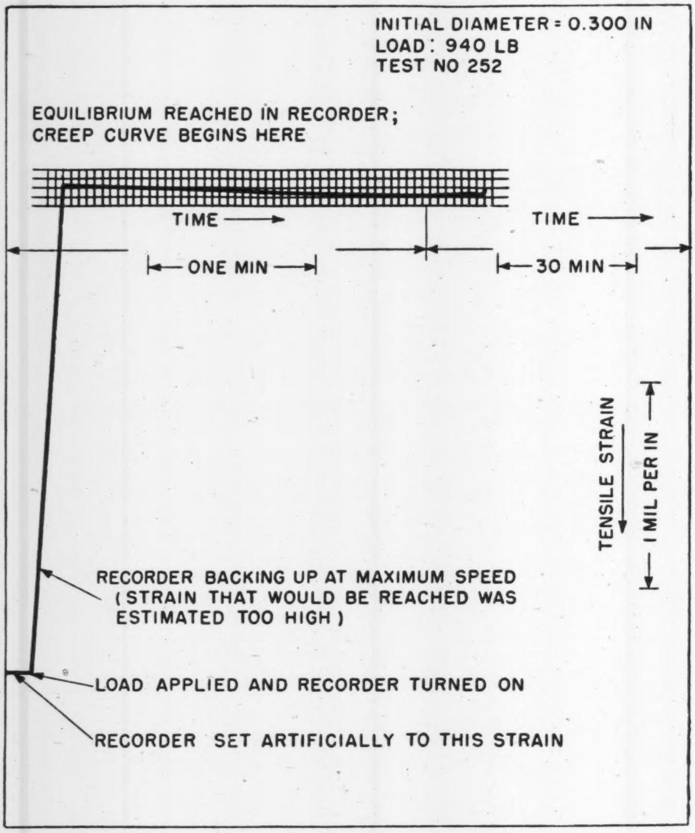

FIG. 25.—Room-Temperature Creep Test on Annealed OFHC Copper.

load due to a sudden rate change (Fig. 26), *n* appears to be about 0.003 ± 0.001 and independent of strain within the same accuracy limits. Although the two values, $n = 0.003$ and $p = -420$, may be in error by as much as 1.5:1 or even 2:1, nevertheless the 3:1 discrepancy between the two *n* values of 0.001 and 0.003 is probably larger than can be explained away by experimental errors. If there were a real, though small, deviation from the behavior expressed by

$$p = -\frac{m}{n},$$

the discrepancy might be explained in terms of a very small tendency of copper to strain-age at room temperature. For the largest rate change of the tests shown in Fig. 26, a transient was observed similar to some noted earlier (11) for 61S-T (Fig. 27). The alloy 61S-T is

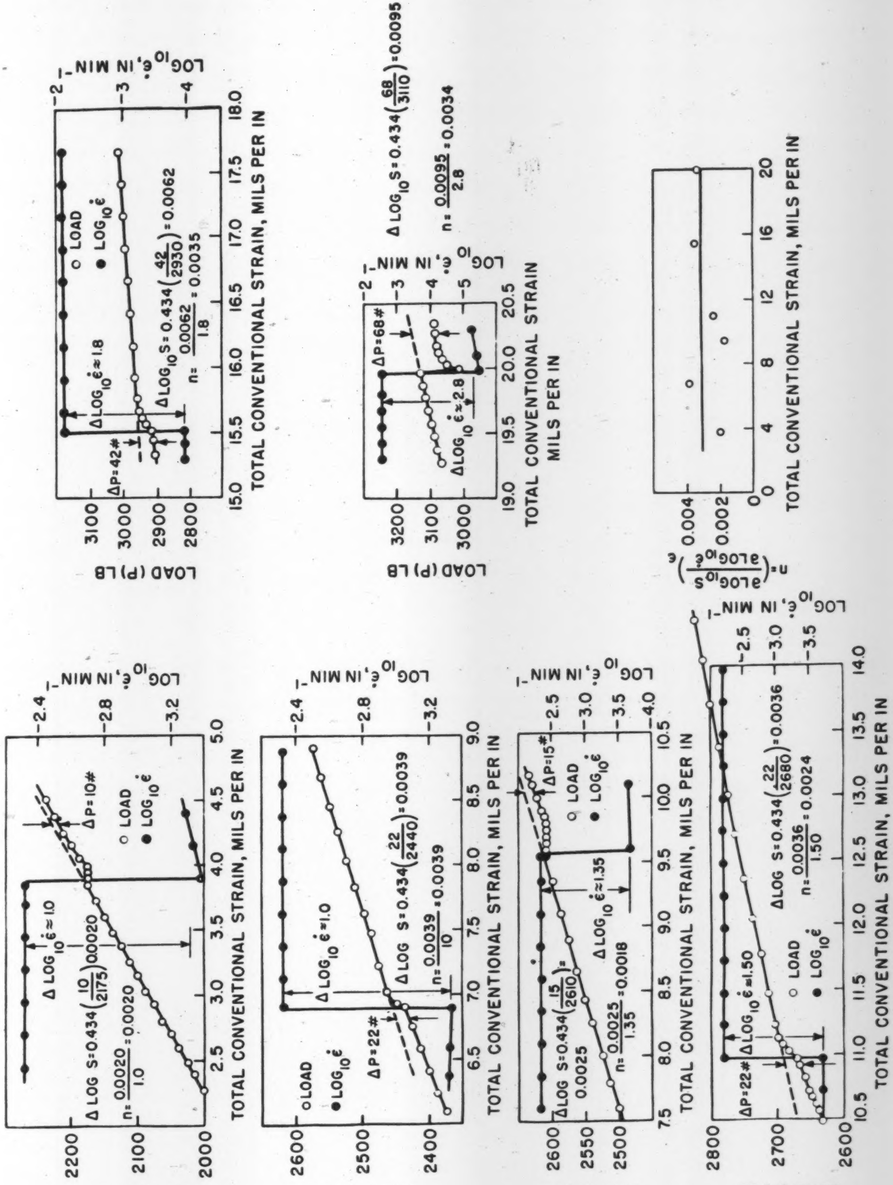

FIG. 26.—Determination of *n* from a Transient Experiment on Annealed Copper at Room Temperature.

known (12) to strain-age at the temperature of the test shown in Fig. 27.

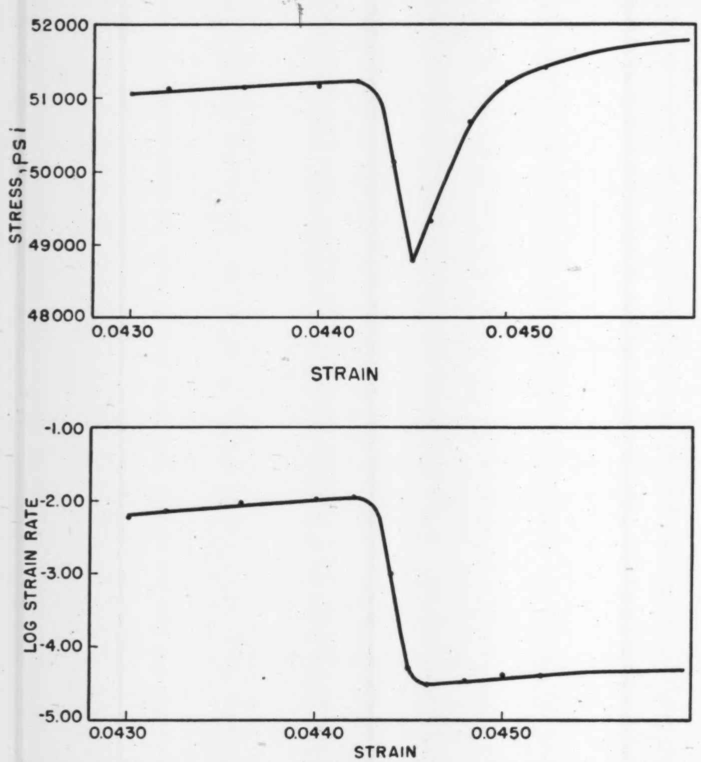

FIG. 27.—Transient Effect Observed in a Tension Test on 61S-T at Room Temperature, from Carreker, Leschen, and Lubahn (11).

If the range of strain were proportional to the strain level, as it appears to be for 61S-T and possibly for annealed copper, one would expect that the range of strain would be much larger for cold-drawn copper rod than for annealed copper for the same strain reached during the creep test. In other words, one would expect that in cold-worked copper the creep rate would decrease much less rapidly with strain than in annealed copper for comparable creep strains. Sturm, *et al* (24), have observed that the slopes of log plastic strain *versus* log time curves for cold worked materials are about 50 per cent greater than for the corresponding annealed materials. These larger slope values correspond to a larger value of p, according to Eq 10, which in turn corresponds to a greater range of strain for a given level of creep strain, as suggested above. Of course, the stress required to produce a given level of creep strain will be much higher in the cold-worked metal than in the annealed metal. Figure 28 shows another example of the greater range of strain in cold-worked metal than in annealed metal for a given level of creep strain. The figure shows that the range of strain for cold-drawn copper is about 0.5 mils per in. at a strain level of 0.6 mils per in. Table I shows that the range of strain in annealed copper for the same strain level is less than 0.05. The difference in behavior is more readily apparent if a creep curve for annealed copper is calculated for the same level of creep strain. The calculation of the shape was based on the value of p of -420 from Fig. 24, and the stress was taken from Table I. The result of this calculation is shown in Fig. 28 by way of contrast with the data on the cold-worked metal. Thus, according to Fig. 28, the generalization that the range of strain is proportional to the strain level extends qualitatively to cold-drawn material, even though the strain introduced by cold drawing differs somewhat in nature (23) from that which would have been introduced during a creep test. That there is a difference in type of strain introduced by stretching and drawing is shown by a different shape of stress-strain curve in subsequent compression (23).

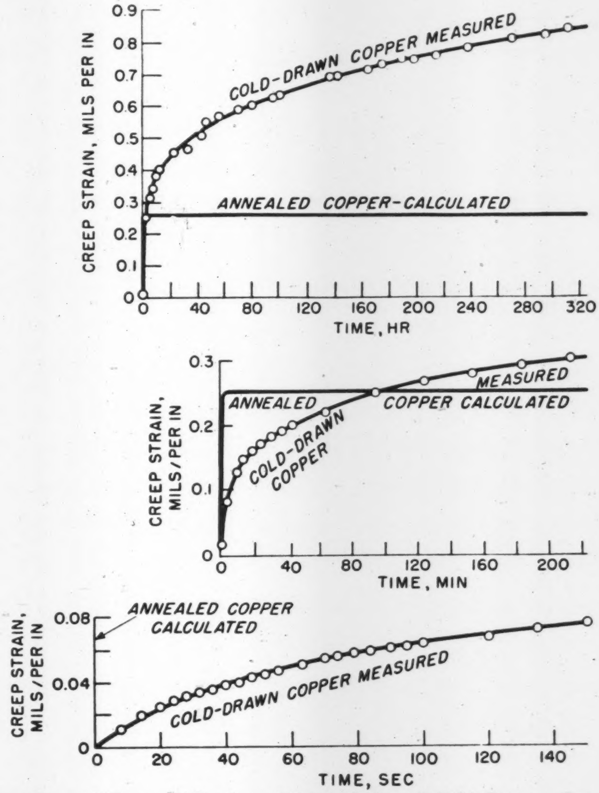

FIG. 28.—Comparison of Creep Behavior of Annealed and Cold-Drawn Copper at Room Temperature and at the Same Level of Creep Strain.

Creep stress for annealed copper = 5000 psi. For cold-drawn copper: 36,000 psi. Lower graphs are magnifications in time of upper graph.

SUMMARY AND CONCLUSIONS

At comparatively low temperatures, the creep rate is initially extremely high, but quickly diminishes to an exceedingly small value. To the casual observer, practically all of the plastic strain appears while applying the load, and then the creep curve levels off abruptly, creep apparently ceasing. Actually it is probable that the creep rate is never either infinite or zero; it only appears that way because the creep rate decreases so rapidly with strain.

The larger the creep load, the larger is the strain at which leveling-off apparently occurs, and the less abruptly the creep curve levels off. The latter effect appears most conspicuously when the creep curves of cold-drawn copper and annealed copper are compared. The creep rate decreases much less rapidly with strain in cold-drawn copper than in annealed copper for a given creep strain.

Annealed copper at strains around 1 per cent has a creep curve that levels off so abruptly that there appears to be no "creep," or gradual strain, at all. At comparable strains, the aluminum alloy 61S-T exhibits creep in amounts easily measurable with present gaging, for the creep rate decreases much less rapidly with strain than in the case of annealed copper. The great difference in creep behavior between 61S-T and annealed copper may be due to the fact that the strain-hardening exponent $m = (\partial \log S/\partial \log \epsilon)_{\dot{\epsilon}}$ of 61S-T is about one-tenth that of annealed copper.

At comparatively low temperatures, the rate sensitivity is so small (of the order of 0.001) that the effect of easily attainable rate differences on the flow stress is smaller than the scattering among specimens. Consequently, it is necessary to measure the rate sensitivity on a single specimen by observing the small offset in the stress-strain curve accompanying a large intentional rate change.

The low-temperature behavior described above is in sharp contrast to high-temperature behavior, where the rate sensitivity is high (of the order of 0.1) and the creep rate decreases much more slowly with strain.

According to previous concepts of creep-tension relations, namely that plastic behavior is independent of prior history, the creep curve at any stress can be obtained by cross-plotting constant-rate tension curves at that stress to obtain a rate-strain curve and thence a strain-time curve. The above procedure is not applicable to low-temperature data because stress-strain curves for different specimens scatter by as much as the effect of large rate differences. On the other hand, tension curves can be constructed from creep curves for 61S-T and annealed copper by cross-plotting constant-stress, rate-strain curves at a given rate. The corresponding relationship is called the "modified Orowan relation."

The creep behavior has now been expressed in terms of a combination of two relationships, one being the modified Orowan relation, and the other being the equation

$$p = -\frac{m}{n},$$

which is another consequence of the hypothesis that strain-rate history has no effect. In this equation, m and n are the strain-hardening exponent and rate sensitivity, respectively, and p is the rate of decrease $(\partial \log \dot{\epsilon}/\partial \log \epsilon)_S$ of creep rate with respect to strain. The equation

$$p = -\frac{m}{n}$$

was found to apply fairly well to the data on annealed copper, although the creep data is not extensive or accurate enough to justify a very strong conclusion.

The equation

$$p = -\frac{m}{n}$$

was in no way applicable to the data on 61S-T. This was attributed to the fact that 61S-T strain ages at room temperature. Copper does not strain-age at room temperature. The above facts require the conclusion that

$$p = -\frac{m}{n},$$

if applicable at all, must be restricted to conditions that exclude strain aging.

It was found for 61S-T that $p = (\partial \log \dot{\epsilon}/\partial \log \epsilon)_S$ is independent of the strain during any particular creep test and independent of the creep load. The data on annealed copper were consistent with this behavior, although not extensive enough to confirm it. Of course the constancy of p for a given material and temperature has by no means been shown to be generally true; but if it were true, it would be a generalization of considerable importance, because then one tension test and a single creep test would suffice to calculate all the creep curves for all the stresses embraced by the tension test, even though the equation

$$p = -\frac{m}{n}$$

might prove to be invalid.

Acknowledgment:

The author would like to express appreciation to H. A. Lequear for helping with the tests and to J. C. Fisher for his interest and encouragement during the investigation. This work received support from the Flight Research Laboratory, Wright Air Development Center.

APPENDIX I

The physical significance of the equation

$$p = -\frac{m}{n}$$

is illustrated by the following considerations, based on the physical picture shown in Fig. 29. During a small increment of strain $d\epsilon$ in a tension test at constant rate, there is a small change in stress dS_1 owing to strain hardening. These changes occur in going from A to B in Fig. 29. If the rate were suddenly changed at B, there would be a change in stress because of the rate sensitivity. In particular, if a certain rate change $d\dot{\epsilon}$ were used, the corresponding change in stress dS_2 could be made equal to $-dS_1$, that is, the negative of the stress increase due to strain hardening. These changes occur in going from B to C in Fig. 29. In going from A to C by the above path, there has been no net change in stress.

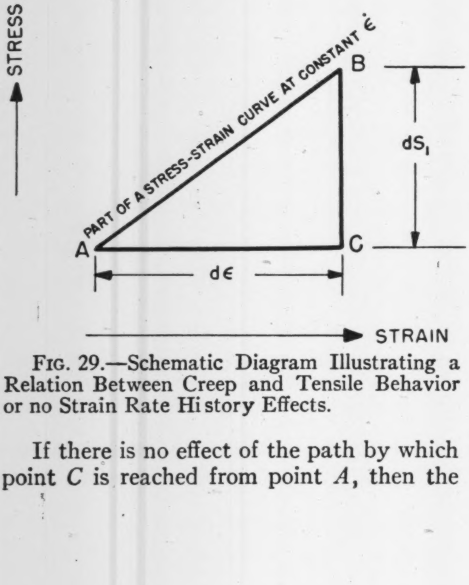

FIG. 29.—Schematic Diagram Illustrating a Relation Between Creep and Tensile Behavior or no Strain Rate History Effects.

If there is no effect of the path by which point C is reached from point A, then the behavior at C following path ABC should be the same as if the path AC had been followed. The path AC represents a portion of a creep test, where a change in rate $d\dot{\epsilon}$ accompanies an increase in strain $d\epsilon$ at constant stress. AB represents a portion of a constant-rate tension test, and BC represents a "transient experiment" so called because transient effects often occur in such an experiment (11).

From the condition imposed that

$$dS_2 = -dS_1$$

it follows that

$$\frac{\left(\dfrac{dS_1}{d\epsilon}\right)}{\left(\dfrac{dS_2}{d\epsilon}\right)} = -\left(\frac{d\dot{\epsilon}}{d\epsilon}\right).$$

Using partial derivative notation

$$\frac{\left(\dfrac{\partial S}{\partial \epsilon}\right)_{\dot{\epsilon}}}{\left(\dfrac{\partial S}{\partial \dot{\epsilon}}\right)_{\epsilon}} = -\left(\frac{\partial \dot{\epsilon}}{\partial \epsilon}\right)_S$$

or in the equivalent form involving the logarithms of the quantities:

$$\frac{\left(\dfrac{\partial \log S}{\partial \log \epsilon}\right)_{\dot{\epsilon}}}{\left(\dfrac{\partial \log S}{\partial \log \dot{\epsilon}}\right)_{\epsilon}} = -\left(\frac{\partial \log \dot{\epsilon}}{\partial \log \epsilon}\right)_S$$

If there is any effect of the path by which point C is reached from point A, then this relation will be different, but Fig. 29 shows that it will still involve the same quantities.

APPENDIX II

If p were constant during a creep test and the same for creep tests at different loads, the entire family of creep curves for other stresses could be conveniently calculated from one measured creep curve. The stress to be associated with each curve can be calculated from a single tension test if the modified Orowan relation is assumed valid. One creep test suffices to determine p. If p is constant during the test, the relation between rate and strain is

$$\log \dot{\epsilon} = \log A + p \log \epsilon \qquad \text{.......(8)}$$

where A is a constant. Rearranging:

$$\dot{\epsilon} = A\epsilon^{p} = \frac{d\epsilon}{dt} \qquad \text{............(9)}$$

By integrating and imposing the boundary condition that $\epsilon = 0$ when $t = 0$, Eq 9 becomes

$$\epsilon = [At(1 - p)]^{1/1-p} \qquad \text{........(10)}$$

Thus, for a known value of p, a family of creep curves can be obtained in which the parameter is A. Each curve has associated with it a particular value of creep stress that can be found from a stress-strain curve using the modified Orowan relation. For each creep curve, the creep strain will have a certain value when the creep rate has diminished to the tension test strain rate. If this strain is looked up on the stress-strain curve for the tension test, a corresponding value of stress is obtained. This stress is the creep stress to be associated with the creep curve in question.

Although the modified Orowan relation and the relation

$$p = -\frac{m}{n}$$

both are necessary for the above calculation, and although both stem from the same hypothesis that deformation behavior is independent of prior strain rate, nevertheless the two relations are quite independent of each other. The quantity p governs the interrelation of shape and position ("leveling-off strain") of the creep curves being calculated; and so

$$p = -\frac{m}{n},$$

which yields the value of p from quantities measured in a tension test, governs the relation between shape and position. The relation between stress and position on the other hand, is expressed by the modified Orowan relation. It is desirable to regard these two relations independently for the time being for two reasons: (1) the evidence supporting the equation

$$p = -\frac{m}{n}$$

is currently almost nil, while there is considerable evidence supporting the modified Orowan relation; and (2) if there are transient effects or other effects of rate history, it seems reasonable to suppose that such different types of relations would be affected differently, the one possibly being influenced greatly while the other is negligibly affected.

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DISCUSSION

MR. FRED STIRBL.[1]—There is a need for a more specific designation for the 61S-T alumiuum alloy. Without inclusion of temper designations such as T4, T5, or T6, the alloy is not properly defined.

MR. J. D. LUBAHN (*author*).—The paper specifically states at every point where the aluminum alloy is mentioned that it is 61S-T. This designation is a standard nomenclature used by the Aluminum Company of America, and the artificial aging treatment resulting in this temper can be found in standard handbooks.

The Aluminum Company's handbook calls for the following heat treatment for the 61S-T temper: Solution treated at 960 to 980 F, quenching in cold water, and precipitation hardening treatment either 16 to 20 hr at 315 to 325 F or 6 to 10 hr at 345 to 355 F.

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THE INFLUENCE OF PERIODIC OVERSTRESSING ON THE CREEP PROPERTIES OF SEVERAL HEAT-RESISTANT ALLOYS*

By G. J. Guarnieri[1] and L. A. Yerkovich[1]

Synopsis

Because of the intermittent overloads encountered in the operation of jet aircraft, certain problems have arisen in predicting the life expectancy of structural materials exposed to high temperature service conditions. The intent of this investigation is to provide exploratory data capable of evaluating the significance of the variables controlling the cyclic load creep properties of heat resistant alloys.

Test equipment and procedures were developed for conducting overload tests under conditions similar to those encountered in turbojet aircraft during maneuvering. Overload tests were conducted on a type 347 stainless steel at 1200 and 1500 F for various normal stress levels with overstress to normal stress ratios of 1.2, 1.5, and 3.0. The overstress was applied for 5, 10, and 25 per cent of the total test time. Similar sets of overstress tests were performed for N-155 alloy at 1500 and 1800 F and for H.S. 21 type alloy at 1500 F. The overstress was applied at a normal stress ratio of 1.66 for 5, 10, and 25 per cent of the test time.

It was possible to correlate the results obtained into convenient design charts which relate the variables of stress, time, temperature, ratio of overstress to normal stress, and time percentage of overstress application.

A method for calculating overstress characteristics from static load creep test data was explored, and acceptable agreement was obtained with experimental results.

The laboratory development of heat resistant alloys for high temperature service has been achieved primarily through the use of constant temperature-constant load creep and rupture tests. In addition, practically all design data for structural use of such materials have been determined by similar types of tests. Such creep data have been used with considerable success for designs of structures operating under fairly steady stress and temperature conditions of known magnitudes. Even where service temperatures and loads are subject to periodic fluctuations, satisfactory utilization of materials has been accomplished through consideration of the peak operrating temperature and stress.

In the case of aircraft turbojet service, there are at least two operating circumstances which may alter the life expectancy of a material based upon normal or average conditions. One is the overheating of engine parts well above the usual temperature. Another is the abnormal loading at elevated temperatures of component parts as might be encountered in occasional acceleration demands. It is with the latter situation that this investigation has been concerned.

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In order to achieve efficient design which makes maximum use of metal thickness, excessive safety factors cannot be tolerated as a means of compensating for the unknown effects resulting from periodic overload conditions. A need exists for defining the extent to which this variable influences allowable working stresses for high temperature alloys.

As a first approximation, the creep behavior of alloys subjected to cyclic overload conditions might be estimated from their static stress characteristics. However, a number of complications arise which are not necessarily predictable from these static test data. The rate at which creep occurs in an alloy at a particular instantaneous stress depends to a great degree not only upon the present stress and temperature conditions, but also upon its past stress, temperature, time, and deformation history. This is to say, the particular state to which a metal is worked will influence its future creep behavior. Transient plastic deformation, noted by Carreker, Leschen, and Lubahn[2] illustrates one form of this behavior.

Alloy	Composition, per cent													
	C	Mn	Si	S	P	Cr	Ni	Cb	Cu	Mo	W	Co	N	Fe
347	0.074	1.62	0.35	0.018	0.015	17.60	11.03	0.77	0.08	...	...	...	...	bal.
H. S. 21 type alloy	0.26	0.45	0.38	...	...	26.75	1.49	...	...	5.83	...	bal.	...	...
N-155	0.20 max.	...	...	...	...	20.00	20.00	1.00	...	3.00	2.50	20.00	0.15	bal.

There is at present a need for design creep data based upon cyclic load conditions applicable to turbojet service operation. For this case of overstressing, consideration must be given to such factors as of ratio of overstress to normal stress, of percentage of total time the overstress is applied, and of time pattern of overstressing. This investigation has been made with the objective of devising overload creep testing techniques and applying such techniques in evaluating the effects of the above noted variables on the creep and rupture properties of several commercial heat resistant alloys.

The program has been conducted under the sponsorship of the Department of the Navy, Bureau of Aeronautics, Materials and Equipment Branch.

MATERIALS TESTED

An annealed low-carbon N-155 alloy sheet material of 0.055-in. thickness was used for overload testing at 1500 and 1800 F. Precision cast H.S. 21 type alloy specimens were similarly investigated at 1500 F. AISI type 347 stainless steel annealed in sheet form of 0.050-in. thickness was tested to provide representative data for the 1200 F to 1500 F temperature range.

The chemical compositions of these alloys as listed below represent the actual analyses for type 347 stainless steel and H.S. 21 type alloy. Nominal composition is represented for the N-155 alloy.

TEST METHODS AND APPARATUS

The test equipment consists basically of a conventional lever type creep apparatus to which have been added facilities for superimposing additional stress or overloads on the test specimen for desired time periods. Various timing devices are employed to regulate the overstress cycles as well as the time intervals between them. The test temperature is maintained with a resistance-wound creep furnace regulated by a conventional potentiometric temperature control system which allows the test temperature to be held within limits of ±3 F of the normal value over a 2-in. gage section.

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[2] R. P. Carreker, J. G. Leschen, J. D. Lubahn, "Transient Plastic Deformation," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 180, pp. 139–146 (1949).

A set of extensometers attached to the specimen in conjunction with a cantilever SR-4 strain gage system determines the deformation of the test section.[3] A continuous record of the strain is made on a Dynalog type strain recorder with an accuracy of 0.0002 in. per in. and a sensitivity of 0.00002 in. per in.

Overstressing is accomplished by suspending a calculated load at a 5 to 1 ratio postion on the loading lever, normal loading being applied at a 10 to 1 ratio point. Since the overstressing is an intermittent operation, the overload must be applied and removed for each cycle. This is performed by means of a gear-motor screw jack which raises and lowers a weight platform directly beneath the 5 to 1 lever position.

Figure 1 is a schematic diagram of the overload control circuit. As illustrated, the overload weight holder and the screw jack platform are integral parts of the electrical circuit. The application and removal of overstress are controlled by the demands of the schedule and duration timers which determine the frequency as well as the duration of overstressing.

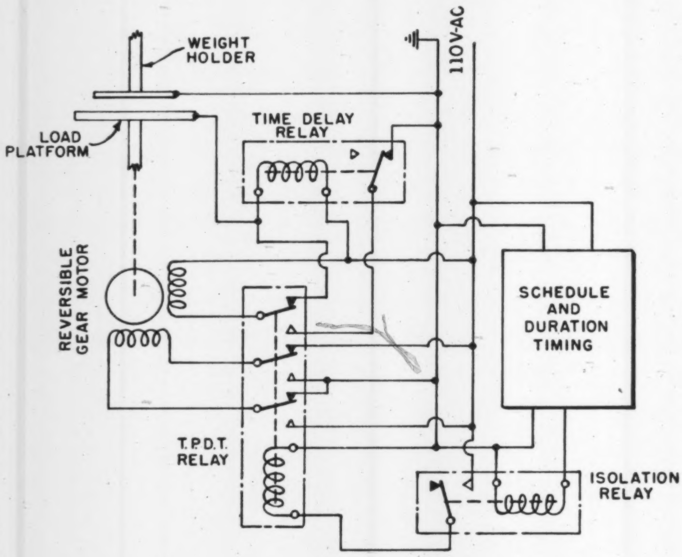

FIG. 1.—Schematic Diagram of Overload Control Circuit.

EVALUATION OF OVERSTRESSING TIME PATTERN

If the ratio of the over-all expected time of overload operation to the normal load time were to be used as a design criterion in determining limiting stress values, it would become important to consider the effect of the many possible sequences of overloading which could produce the same percentage time duration of overload. Consequently, this variable was investigated by preliminary experiments with the type 347 stainless steel at 1200 and 1500 F, using a variety of overload time patterns. Figure 2 illus-

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[3] G. Guarnieri and J. Miller, "A Cantilever Strain Gage for High Temperature Tensile and Creep Testing of Sheet Materials," *Metal Progress*, Vol. 54, pp. 692–694, November, 1948.

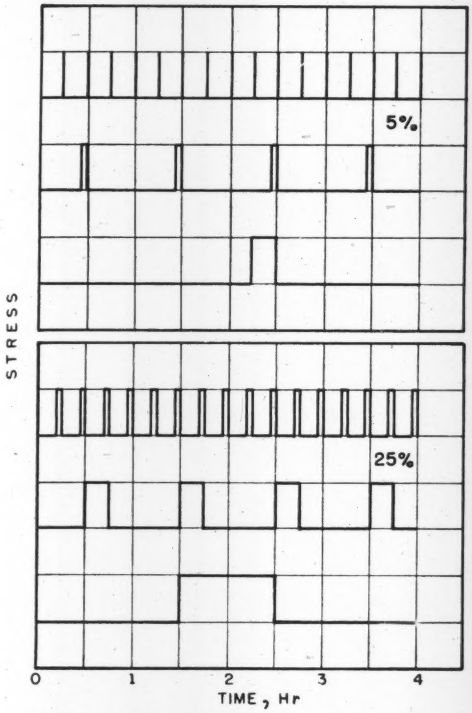

FIG. 2.—Various Stress-Cycle Patterns for 5 and 25 per cent Durations of Overstressing.

trates graphically the various time-stress patterns used to give overstress durations of 5 and 25 per cent. Overstressing durations ranged from 0.75 min per 15 min to 15 min per 5 hr for the 5 per cent duration tests and 3.75 min per 15 min to 1 hr per 4 hr for the 25 per cent duration tests.

For this series of overload tests conducted to determine the effect of the overstressing time pattern, Table I furnishes the creep and fracture characteristics of type 347 stainless steel under the specific test conditions. These overstress results are summarized in Fig. 3.

In tests conducted at 1200 F, where the percentage of total time of overstressing was held constant, it was found that for a variety of time patterns, only minor differences were noted in the creep behavior of type 347 stainless steel after application of the first overload. At 1500 F, under similar conditions, insignificant differences resulted. This conclusion holds true for both the 5 per cent duration and the relatively longer

TABLE I.—EFFECT OF VARIOUS OVERLOAD TIME PATTERNS ON CREEP-RUPTURE PROPERTIES OF TYPE 347 STAINLESS STEEL SHEET, ANNEALED.

Temperature, deg Fahr	Normal Stress, psi	Overload Stress, psi	Ratio, Overload Stress to Normal Stress	Time of Overload, per cent	Overload Cycle	Time for Creep, hr					Time of Test, hr	Elongation, per cent
						0.2 per cent	1 per cent	2 per cent	5 per cent	Fracture		
1200	25 000	37 500	1.5	5	0.75 min per 15 min	F.O.[a]	F.O.[a]	F.O.[a]	39.5	78.0	78.0	7.8
				5	3 min per hr	"	"	"	25.0	54.25	54.25	9.5
				5	15 min per 5 hr	"	"	"	F.O.[a]	47.75	47.75	10.3
				25	3.75 min per 15 min	"	"	"	7.0	27.75	27.75	7.8
				25	15 min per hr	"	"	"	1.5	23.5	23.5	8.3
				25	1 hr per 4 hr	"	"	"	6.75	37.0	37.0	7.97
1500	7 000	10 500	1.5	5	0.75 min per 15 min	1.1	5	10.5	20.0	32.0	32.0	12.0
				5	3 min per hr	1.5	6.5	11.5	21.5	37.75	37.75	14.0
				5	15 min per 5 hr	2.0	7.5	12.6	24.5	36.5	36.5	9.7
				25	3.75 min per 15 min	F.O.	5.5	9.3	17.0	21.5	21.5	9.0
				25	15 min per hr	0.75	3.75	6.75	14.3	21.75	21.75	9.5
				25	1 hr per 4 hr	2.2	6.0	10.0	18.0	26.5	26.5	10.9

[a] F.O. = First Overload.

25 per cent duration overstressing cycles.

OVERLOAD TEST RESULTS

Having determined that the time pattern of overstressing has negligible effect on the overstressing creep properties of type 347 stainless steel as long as the time percentage of overstressing remains constant, test schedules were planned to permit overstressing to be accomplished hourly. The duration of the overstress periods was varied to give overload cycles amounting to 5, 10, and 25 per cent of the total test time. In the series of overstress tests conducted, the resulting creep characteristics were correlated with static load creep data to indicate the extent to which creep deformation and rupture is accelerated. Static creep and rupture reference data which define the normal stress and overstress limits were determined for evaluation of overstress results on the three alloys studied. The constant load-constant temperature properties of these materials are listed in Table II.

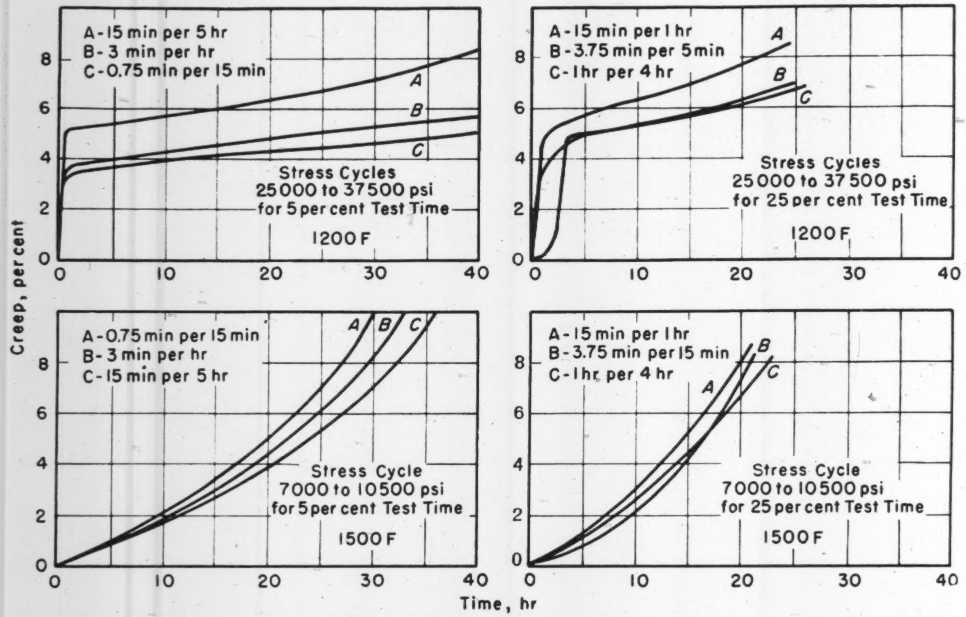

FIG. 3.—Comparisons of Type 347 Stainless Steel Time-Deformation Curves for Various Stress-Cycle Patterns at Constant Time Percentages of Overstressing.

The data presented in Table III represent the creep behavior of the materials under the specified overstress test conditions. Typical time-deformation curves are illustrated in Fig. 4. In this particular set of tests on type 347 stainless steel, overstress to normal stress ratios of 3.0 and 1.5 at 1500 F are represented. The extent to which the creep deformation was accelerated by the overload applications may be estimated by comparison with the constant load tests.

Since creep rates vary exponentially with stress, it is not surprising to find that creep and fracture times rapidly approach those corresponding to the overstress values even for small time percentages of overstress application.

This is especially true at the larger overstress to normal stress ratios. For tests performed on type 347 stainless steel at 1500 F for a normal stress of 4000 psi and an overstress ratio of 3.0, approximately 90 per cent of the total creep occurred during the overstressing periods.

TABLE II.—STATIC CREEP AND RUPTURE TEST DATA.

Temperature, deg Fahr	Stress, psi	Time for Creep, hr					Time of Test, hr	Elongation, per cent	Minimum Creep Rate, per cent per hr
		0.2 per cent	1 per cent	2 per cent	5 per cent	Fracture			
				347 STAINLESS STEEL					
1200	20 000	20.0	450.0	775.0	...	996.0	996.0	3.56	0.00112
	22 500	3.0	140.0	357.0	...	389.0	389.0	3.0	0.00378
	25 000	...	60.0	167.0	...	210.0	210.0	3.50	0.00936
	30 000	...	...	.8	70.0	75.2	75.2	5.58	0.0260
1500	3 000	17.0	88.0	173.0	438.0	623.0	623.0	8.75	0.0010
	4 000	6.8	35.0	64.0	150.0	360.0	360.0	35.0	0.0143
	5 000	...	26.5	41.7	86.7	149.0	149.0	16.50	0.0288
	7 000	2.7	11.7	20.5	38.5	55.0	55.0	11.0	0.0600
	10 000	0.2	2.5	4.2	7.1	11.5	11.5	13.50	0.300
	12 000	0.08	0.9	1.65	3.3	5.3	5.3	12.0	1.0
	15 000	<0.02	0.13	0.28	0.65	1.1	1.1	11.0	6.9
				N-155 ANNEALED					
1500	10 000	10.0	805.0	1180.0	...	1297.0	1297.0	4.0	0.00101
	13 000	9.2	188.0	266.0	380.0	428.75	428.75	12.0	0.00447
	15 000	...	50.0^a	...	116.0^a	200.0^a	...	...	0.0078
	16 670	...	15.0^a	30.0^a	53.5^a	90.0^a	...	...	...
	20 000	0.2	2.0	4.2	9.8	24.0	24.0	28.5	0.0474
	21 670	...	0.9^a	2.8^a	6.1^a	14.0^a	...	...	...
	25 000	0.1	0.4	0.8	1.9	4.75	4.75	16.0	2.64
	33 340	...	0.04	0.08	0.2	0.75	0.75	28.0	25.00
1800	3 000	11.5	354.0	714.0	...	909.0	909.0	4.0	0.00280
	4 000	...	75.0^a	121.6^a	...	200.0^a	...	...	...
	4 800	...	27.0^a	45.0^a	78.2^a	85.0^a	...	...	...
	5 000	5.75	23.75	38.0	67.5	68.5	68.5	7.0	0.0180
	6 000	2.0	6.0	9.6	17.3	26.6	26.6	11.0	0.0720
	6 400	...	4.30^a	7.75^a	15.0^a	20.0^a	...	...	...
	8 000	...	1.30^a	2.30^a	4.3^a	5.9^a	...	...	...
	9 600	...	0.45^a	0.80^a	1.6^a	2.8^a	...	...	...
				AS CAST H.S. 21 TYPE ALLOY					
1500	18 000	3.7	45.0	194.0	...	256.3	256.3	6.0	0.006
	21 000	0.6	4.6	17.0	...	59.5	59.5	6.5	0.080
	25 000	0.4	2.4	6.0	23.0	33.75	33.75	9.0	0.150
	30 000	0.15	0.9	2.1	8.4	13.5	13.5	10.0	0.420
	35 000	0.075	0.5	1.5	4.85	5.3	5.3	13.0	0.790

[a] Extrapolated or interpolated from stress time curves.

Under similar test conditions with a ratio of 1.5, the effect of the overstress is not so pronounced. A comparison of the 5000 to 15,000 psi and 10,000 to 15,000 psi curves in Fig. 4 demonstrates the influence of the normal stress inasmuch as the overstresses are identical in both cases.

From a practical standpoint, a system of presenting overstress data in the form of suitable design charts would be desirable. Figure 5 is an example of one such type of chart in which the creep and rupture life *versus* the per cent of overstress application is presented for a particular combination of normal and overload stresses at a constant temperature. With this selection of coordinates, life expectancies may be determined by interpolation for per cent times of overstressing other than those obtained experimentally.

A more conventional type of stress-time diagram has been used to summarize the overstress creep and fracture data

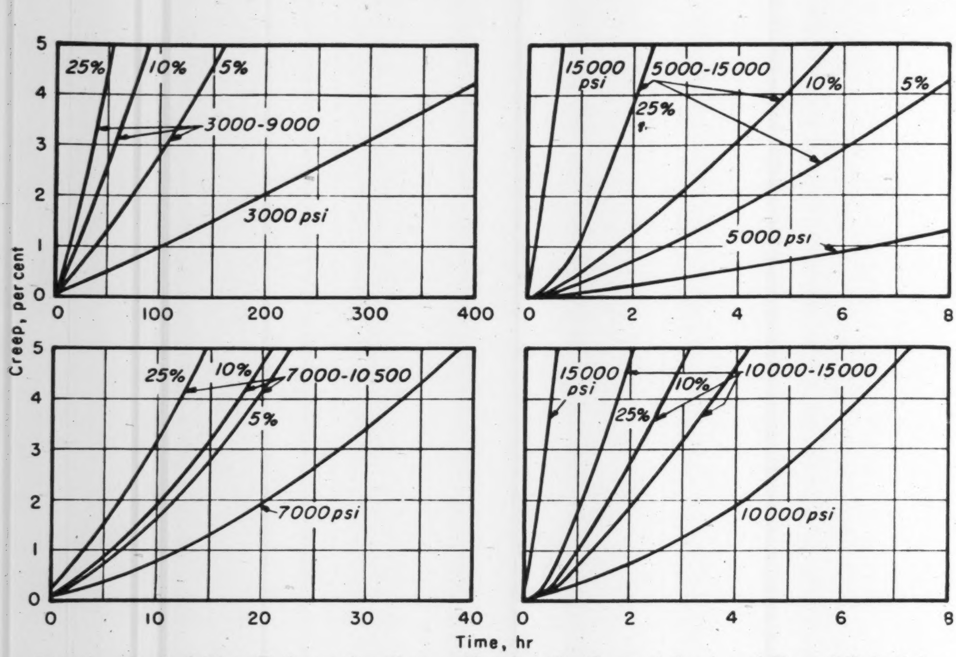

FIG. 4.—Typical Time-Deformation Curves Showing the Creep Behavior of Type 347 Stainless Steel. Overstressed 5, 10, and 25 per cent of the time at 1500 F.

Overstress to normal stress ratios of 3.0 and 1.5.

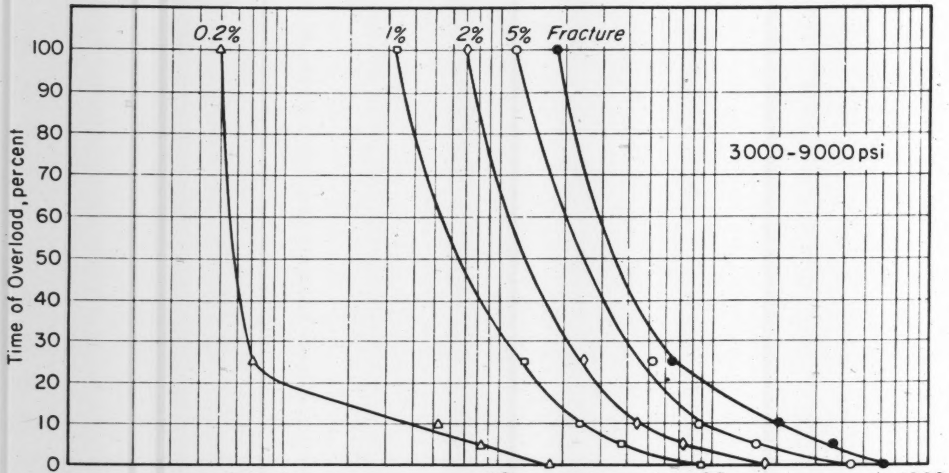

FIG. 5.—Variation of Creep and Fracture Times with per cent of Overstress Application.

Typical curves for type 347 stainless steel at 1500 F for overstress to normal stress ratio of 3.0.

for the 347, N-155, and H.S. 21 type alloys studied. In Figs. 6 through 10 are plotted the normal stress-time relationships for various amounts of creep and rupture. Each chart represents a constant normal to overload stress ratio and a particular creep or rupture condition for a given material. The various stress-time lines within each chart correspond to various percentages of time the overload might be applied. Thus from such a data sheet it should be possible to predict limiting stress values for a material exposed to high temperature overload service where it is possible to estimate the approximate ratio of overstress to normal stress and the percentage of time the overstress will be applied.

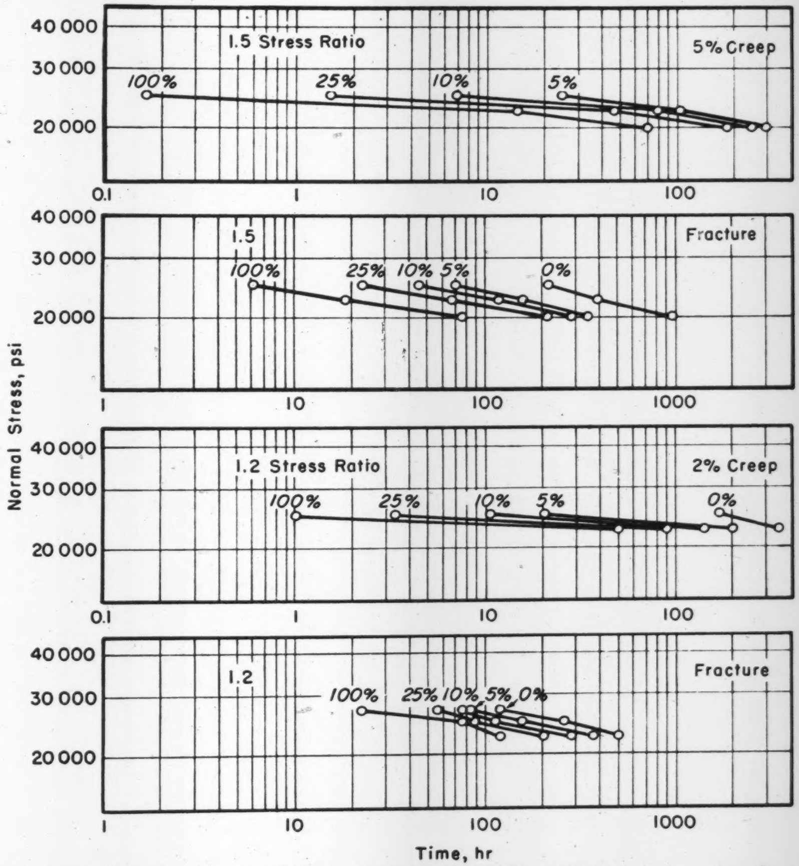

FIG. 6.—Type 347 Stainless Steel Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratios of 1.5 and 1.2, Overstressed 5, 10, and 25 per cent of the Time at 1200 F. The 0 and 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

In view of the plentiful supply of constant load-constant temperature creep and rupture data available for heat resistant alloys, there would be a definite advantage in being able to determine either graphically or analytically the overload creep characteristics from the conventional constant load data. Several methods of calculation were tried, using the results obtained from this investigation, and fair agreement was found between calculated times for specific amounts of creep or fracture and those determined experimentally from overstress tests. The simplest and most convenient procedure employed for making such calculations involved the use of the static stress-time line for a given per cent total creep. With these data "average" creep rates V_o and V_n were determined as the ratio of the total creep e to the time t for both the overload and normal stresses respectively. These rates, when multiplied by the respective time fractions kt and $(1 - k)\,t$ that the overstress and normal stress were applied, yielded

TABLE III.—OVERSTRESS CREEP TEST RESULTS.

Temperature, deg Fahr	Normal Stress, psi	Overload Stress, psi	Ratio, Overload Stress to Normal Stress	Time of Overload, per cent[a]	Time for Creep, hr					Time of Test, hr	Elongation, per cent
					0.2 per cent	1 per cent	2 per cent	5 per cent	Fracture		
Type 347 Stainless Steel Sheet, Annealed											
1200	22 500	27 000	1.2	25	F.O.[b]	6.5	90.5	...	204.75	204.75	3.9
	25 000	30 000	1.2	25	0.15	F.O.	3.5	...	81.5	81.5	4.1
	27 000	32 400	1.2	25	...	F.O.	F.O.	28.0	57.5	57.5	9.0
	20 000	30 000	1.5	25	F.O.	F.O.	7.0	232.0	244.75	244.75	5.42
	22 500	33 750	1.5	25	F.O.	F.O.	F.O.	51.0	91.5	91.5	7.52
	25 000	37 500	1.5	25	0.17	F.O.	F.O.	1.5	23.5	23.5	8.3
1200	22 500	27 000	1.2	10	F.O.	25.5	178.0	...	292.0	292.0	3.5
	25 000	30 000	1.2	10	0.2	F.O.	15.0	...	109.5	109.5	4.0
	27 000	32 400	1.2	10	...	F.O.	F.O.	55.5	75.5	75.5	7.0
	20 000	30 000	1.5	10	F.O.	F.O.	15.5	...	174.5	174.5	7.5
	22 500	33 750	1.5	10	F.O.	F.O.	F.O.	58.0	68.5	68.5	8.0
	25 000	37 500	1.5	10	0.25	F.O.	F.O.	6.75	60.5	60.5	12.5
1200	22 500	27 000	1.2	5	F.O.	18.0	166.5	...	468.5	468.5	4.2
	25 000	30 000	1.2	5	0.17	F.O.	10.75	...	206.5	206.5	6.0
	27 000	32 400	1.2	5	...	F.O.	F.O.	61.75	83.5	83.5	6.5
	20 000	30 000	1.5	5	F.O.	F.O.	6.5	290.0	343.5	343.5	9.0
	22 500	33 750	1.5	5	F.O.	F.O.	F.O.	118.0	167.5	167.5	7.0
	25 000	37 500	1.5	5	0.2	F.O.	F.O.	25.0	54.25	54.25	9.5
1500	4 000	6 000	1.5	25	3.0	30.0	60.0	142.0	214.5	214.5	9.07
	7 000	10 500	1.5	25	F.O.	3.75	6.75	14.3	21.75	21.75	9.5
	10 000	15 000	1.5	25	...	F.O.	F.O.	1.66	4.5	4.5	19.5
	3 000	9 000	3.0	25	F.O.	13.0	25.0	51.7	64.5	64.5	8.3
	4 000	12 000	3.0	25	F.O.	3.7	6.7	14.1	27.5	27.5	17.0
	5 000	15 000	3.0	25	F.O.	F.O.	F.O.	1.70	4.5	4.5	17.0
1500	4 000	6 000	1.5	10	7.5	40.5	69.5	148.5	316.5	316.5	15.0
	7 000	10 500	1.5	10	1.5	5.75	10.75	20.75	22.0	22.0	9.5
	10 000	15 000	1.5	10	0.25	0.5	1.5	3.4	6.1	6.1	16.0
	3 000	9 000	3.0	10	5.25	24.25	44.0	87.0	205.25	205.25	18.5
	4 000	12 000	3.0	10	1.0	6.3	11.3	23.4	46.25	46.25	15.0
	5 000	15 000	3.0	10	F.O.	1.65	2.6	5.6	14.5	14.5	19.5
1500	4 000	6 000	1.5	5	14.5	52.0	95.0	196.5	403.0	403.0	15.5
	7 000	10 500	1.5	5	1.75	6.75	11.6	21.75	37.75	37.75	14.5
	10 000	15 000	1.5	5	0.25	0.75	2.0	4.2	10.5	10.5	26.0
	3 000	9 000	3.0	5	8.5	37.0	73.0	159.0	371.5	371.5	16.6
	4 000	12 000	3.0	5	1.1	7.5	14.5	30.5	71.5	71.5	20.0
	5 000	15 000	3.0	5	F.O.	2.25	4.35	9.0	15.75	15.75	11.5
N-155 Sheet, Annealed											
1500	10 000	16 670	1.66	5	7.5	201.0	320.0	498.0	738.5	738.5	15.0
	13 000	21 670	1.66	5	2.2	17.5	42.0	80.5	153.5	153.5	26.0
	15 000	25 000	1.66	5	1.0	5.5	10.5	22.5	54.0	54.0	27.5
	20 000	33 340	1.66	5	F.O.	F.O.	2.2	3.5	7.25	7.25	27.0
	10 000	16 670	1.66	10	9.5	125.5	192.0	300.0	332.5	332.5	11.0
	13 000	21 670	1.66	10	1.75	9.5	22.0	50.5	99.0	99.0	25.0
	15 000	25 000	1.66	10	F.O.	3.5	6.3	12.6	25.5	25.5	22.0
	20 000	33 340	1.66	10	F.O.	F.O.	F.O.	1.6	5.25	5.25	26.0
	10 000	16 670	1.66	25	3.5	44.5	97.5	162.5	253.5	253.5	14.5
	13 000	21 670	1.66	25	F.O.	3.5	8.0	24.0	52.5	52.5	24.0
	15 000	25 000	1.66	20	F.O.	2.0	3.75	8.5	20.7	20.7	32.0
	20 000	33 340	1.66	25	F.O.	F.O.	F.O.	F.O.	2.5	2.5	38.0
1800	3 000	4 800	1.66	5	38.0	190.5	286.5	...	332.5	332.5	5.0
	4 000	6 400	1.66	5	9.5	25.0	50.0	106.0	116.5	116.5	8.5
	5 000	8 000	1.66	6.66	...	7.0	11.7	23.0	32.5	32.5	12.0
	6 000	9 600	1.66	5	1.5	5.0	7.0	...	11.0	11.0	14.0
	3 000	4 800	1.66	10	12.5	147.5	258.5	...	326.5	326.5	6.5
	4 000	6 400	1.66	10	5.5	19.0	35.5	74.5	92.5	92.5	9.0
	5 000	8 000	1.66	10	2.1	6.5	11.0	21.5	37.5	37.5	8.0
	6 000	9 600	1.66	10	0.7	1.8	5.0	...	14.5	14.5	10.0
	3 000	4 800	1.66	25	3.0	36.0	86.0	...	117.5	117.5	4.5
	4 000	6 400	1.66	25	4.0	13.0	26.0	48.5	59.5	59.5	9.5
	5 000	8 000	1.66	20	1.2	4.0	6.3	12.75	22.5	22.5	16.0
	6 000	9 600	1.66	25	0.7	1.6	2.6	4.7	10.5	10.5	20.5

TABLE III.—*Continued*

Temperature, deg Fahr	Normal Stress, psi	Overload Stress, psi	Ratio, Overload Stress to Normal Stress	Time of Overload, per cent[a]	Time for Creep, hr					Time of Test, hr	Elongation, per cent
					0.2 per cent	1 per cent	2 per cent	5 per cent	Fracture		
				AS CAST H.S. 21 TYPE ALLOY							
1500	15 000	25 000	1.66	25	0.7	6.6	18.75	78.5	92.5	92.5	7.0
	18 000	30 000	1.66	25	F.O.	1.75	4.65	17.0	28.75	28.75	9.5
	21 000	35 000	1.66	25	F.O.	0.75	1.75	5.6	8.75	8.75	9.5
	15 000	25 000	1.66	10	1.5	21.5	73.5	218.0	222.5	222.5	6.5
	18 000	30 000	1.66	10	0.75	3.75	9.6	30.0	58.0	58.0	9.0
	21 000	35 000	1.66	10	F.O.	1.60	4.25	. . .	12.0	12.0	5.5

[a] Overload Applied Every Hour.
[b] First Overload.

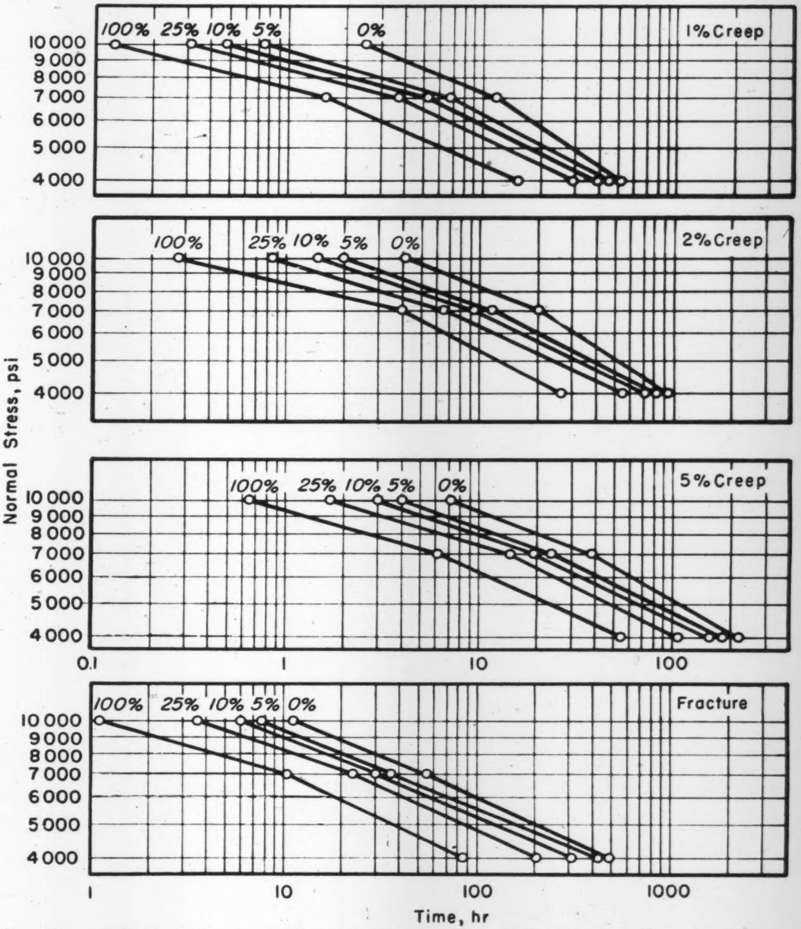

FIG. 7.—Type 347 Stainless Steel Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratio of 1.5, Overstressed 5, 10, and 25 per cent of the Time at 1500 F.

The 0 and 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

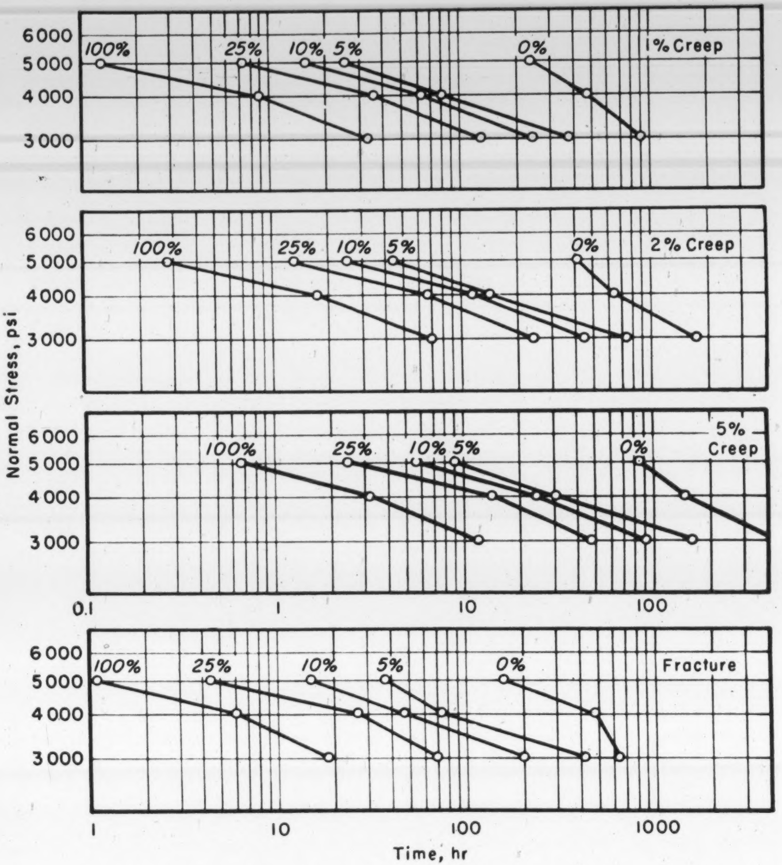

FIG. 8.—Type 347 Stainless Steel Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratio of 3.0, Overstressed 5, 10, and 25 per cent of the Time at 1500 F.

The 0 and 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

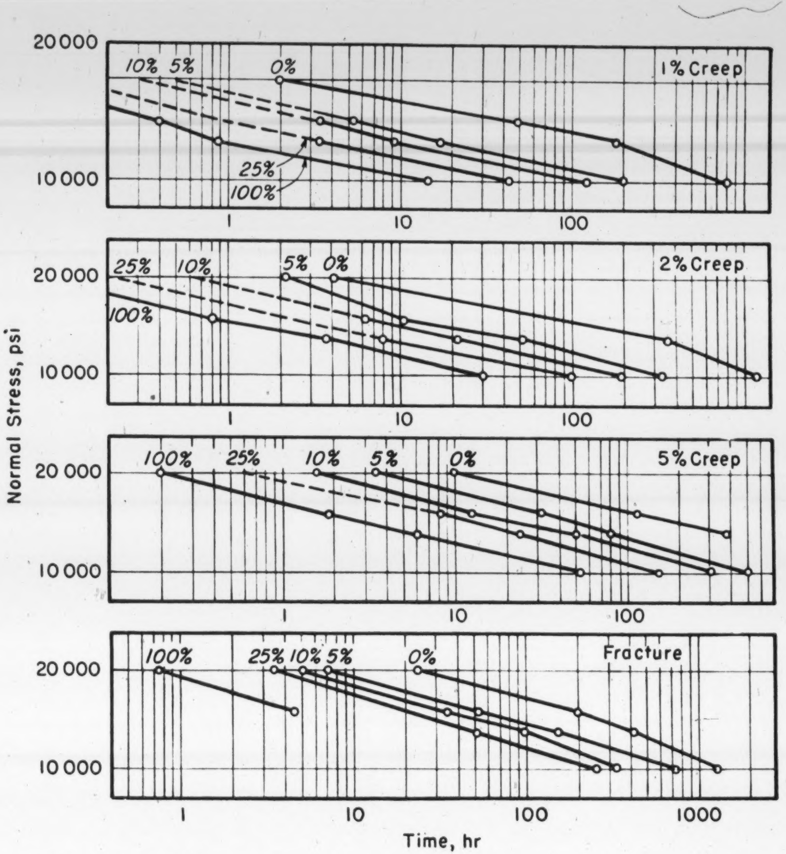

FIG. 9.—N-155 Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratio of 1.66, Overstressed 5, 10, and 25 per cent of the Time at 1500 F.

The 0 and 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

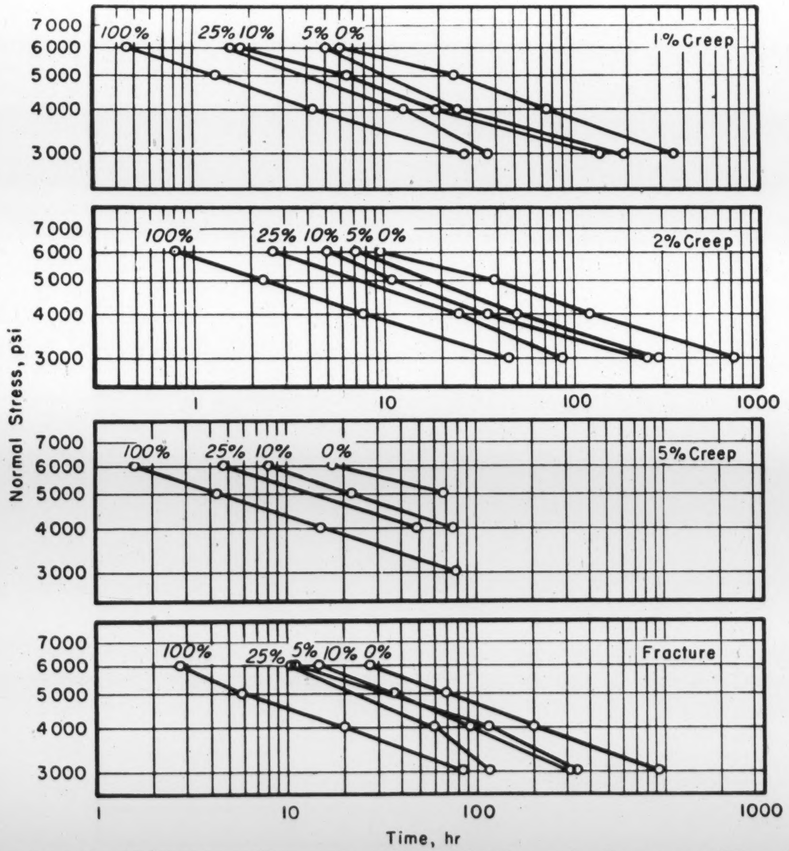

FIG. 10.—N-155 Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratio of 1.66, Overstressed 5, 10, and 25 per cent of the Time at 1800 F.

The 0 ane 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

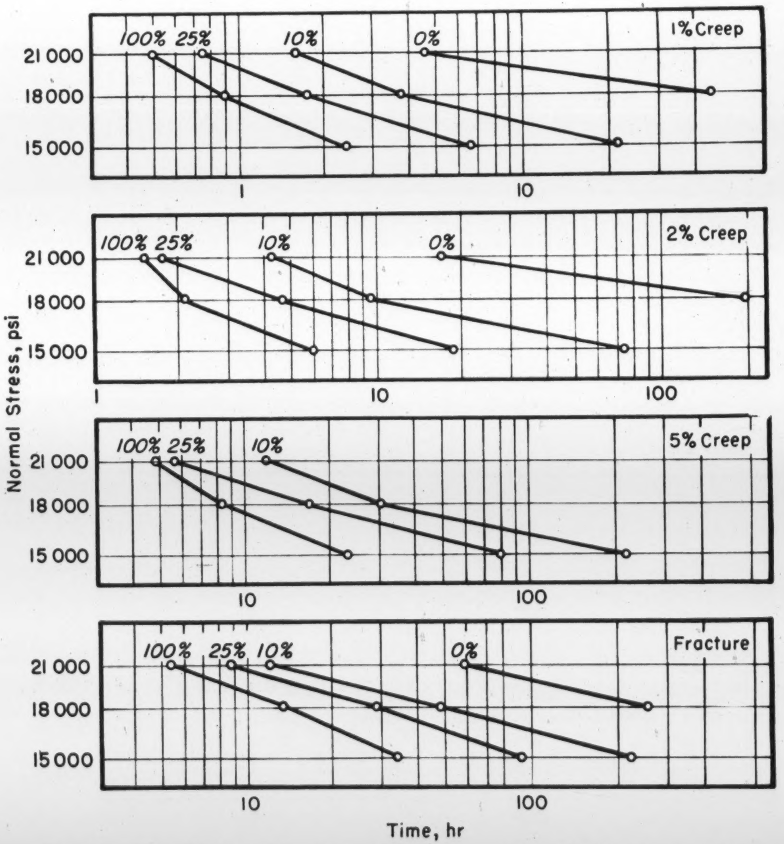

FIG. 11.—H. S. 21 Type Alloy Normal Stress *versus* Time Design Curves for Overstress to Normal Stress Ratio of 1.66, Overstressed 5, 10, and 25 per cent of the Time at 1500 F.

The 0 and 100 per cent lines represent the static stress-time curves for the normal and overload stresses, respectively.

approximate creep quantities which could be related as follows:

Total creep = creep due to overstress + creep due to normal stress.

$$e = V_o(kt) + V_n(1 - k)t$$

$$t = \frac{e}{V_o k + V_n(1 - k)}$$

In the case of fracture time calculations, V_o and V_n were taken as the ratio of the fracture elongation to the fracture times. Values of $\frac{e}{t}$ were calculated and the time was determined graphically from a plot of static load e/t ratio *versus* static load t values. Discrepancies between the calculated times for specified amounts of creep or times for fracture and the experimental results were of the order of 25 to 50 per cent with a few comparisons as high as 100 per cent. However, on a stress basis this amounted to a difference of the order of 5 to 10 per cent.

CONCLUSIONS

The problem of obtaining high temperature design data, suitable for aircraft turbojet materials exposed to periodic overloads, is capable of laboratory solution provided that some understanding be gained of the variables involved. This investigation has served to develop experimental apparatus, test procedures, and methods of data analysis capable of evaluating some of the recognized variables.

It was determined that:

1. For a given ratio of overload time to normal load time, the creep characteristics were not critically affected by various timing patterns of overload application.
2. Applications of overloads for relatively small percentages of the total time produced rapid decrease in creep and rupture life. This was particularly true for the smaller elongation values controlled by primary creep characteristics.
3. Creep and fracture overload design data were determined for type 347 stainless steel at 1200 and 1500 F, N-155 at 1500 and 1800 F, and H.S. 21 type alloy at 1500 F. Various ratios of overload to normal load and a range of time percentages of overload application were incorporated in the evaluation.
4. It was found possible to make acceptable calculations of overload creep characteristics from the static load creep data.

DISCUSSION

Mr. J. D. Marble.[1]—This paper reports an excellent beginning in a new phase of creep-rupture testing, that of simulated service testing. There are two major reasons for testing materials: (1) To compare strengths of various materials under similar conditions in order to select the best or reject that which is unsatisfactory, and (2) to furnish information on the behavior of a particular material under conditions which either simulate those encountered in service or which can be translated into expected service conditions. Of course, the ability to simulate conditions is limited by the factors of cost and time required to achieve these conditions in testing equipment and also by the lack of knowledge of what the service conditions are (which is a major limitation in many cases). Most creep-rupture testing in the past more nearly fits the first classification, while this test series is a definite step into the second group.

The limitation mentioned above requires more definite consideration in this case. The authors have done an excellent piece of work in preparing the data from these tests so that they could be easily applied to service conditions similar to those in the tests. But without an evaluation of actual service conditions in the turbojet application mentioned in the paper, it is difficult to decide how much use can be made of the data presented. Perhaps a more detailed explanation by the authors is in order as to why the particular overstress ratios and time percentages were used in their tests. That is, are there any references which present test data or calculations showing that these are the most likely service conditions? The following questions should probably be relayed to some government agency: How frequently is the overstressing occurring? Is the overstress ratio similar on large sheet metal parts placed axially and smaller stationary radial parts? Does overstressing occur simultaneously with overtemperature or is it a separate phenomenon? What are the overstress ratios encountered in turbojet service? The value to the designer resulting from simulated service testing depends greatly upon how well the service conditions are duplicated in the test or how well the test conditions can be translated into service conditions. Therefore, if it has not been done before, it is hoped that stress measurements under service conditions can be made to outline future testing in this field.

There are two suggestions which should perhaps be made on future test work. The obvious one, of course, is that low creep, longer time information (that is, in the range of 1000 hr) is probably of the most value to the designer. To cover this phase requires much test time, but limited testing of only one or two overstress percentages in this range and discontinuing this type test after 1 or 2 per cent creep would perhaps make the testing program feasible. The other suggestion has to do with comments expressed by many of our turbojet designers to the effect that those in the materials testing field are only furnishing them with information on materials which have already been used to their fullest extent or have already been used and found lacking in expected properties under the severe conditions in turbojets. The designers would like information on new materials or on materials which might be used to a fuller extent in new designs. Of course, those in the materials testing field do not have the necessary time and facilities to investigate all the properties of new alloys before they are used in machine components. But work on the most promising new alloys is probably of much more value to the designer than further data on an alloy which may soon or has already become obsolete.

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[1] Metallurgical Development Unit, Evendale Plant Laboratory, Aircraft Gas Turbine Division, General Electric Co., Cincinnati, Ohio.

The authors showed excellent foresight in their handling of the test data. They presented the test data so that the designer could readily begin to apply the new information in his attempts to achieve full utilization of the material strength. But more important, they attempted to devise a method of calculation whereby conventional constant load data could be used to furnish the overstress information with very little actual overstress testing. They are to be highly commended for this effort.

In the evaluation of overstressing time pattern, it seems that the conclusion that the stress cycle pattern had negligible effect is too hastily drawn. Both Table I and Fig. 3 show that in three of four cases less creep occurred when the periods of overstress and consequently the periods for recovery were longer. And in the fourth case the results of one particular sample were inconsistent with the other two samples of that group. If curve *A* at 1200 F and 5 per cent overload time is not the average of more than two samples, we would suggest that other samples be run. Figure 3 is slightly difficult to analyze because of inconsistent labelling. Of course the differences are not huge, but it depends greatly upon the amount of creep which can be tolerated as to whether the differences are significant. Also, it might be noted that the stresses were perhaps high from the standpoint that 1 per cent creep occurred on the first overload in many cases and in less than 10 hr in all cases. These stresses are certainly greater than operating or design stresses which are usable. Perhaps it is unlikely that any greater effect of time pattern would be noted under lower stresses, but this point should probably be rechecked in future testing. It was wise of the authors to choose one of the shorter time cycles because this is more in the realm of turbojet service.

Our application metallurgists are constantly asking for more complete information on changes in microstructure, hardness, elongation, or fracture appearance with variations in service so that they may better decide to what service a material has been subjected or is capable of being subjected. Therefore, it is hoped that the authors will make some investigation into possible indications produced by the periodic overstressing.

MR. G. B. WILKES, JR.[2] (*by letter*).—The data presented by Guarnieri and Yerkovich is extremely interesting and valuable in design problems with respect to any high-temperature apparatus that does not run at constant speed. They are to be complimented for the thorough coverage of the subject of varying stresses at constant temperature. The writer would like to suggest a modification of their procedure for calculating life or time to any strain from constant stress data. By factoring the strain terms out of their formula

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[2] General Electric Co., West Lynn, Mass.

$$t = \frac{\epsilon}{\frac{\epsilon_0}{t_0} K + \frac{\epsilon_n}{t_n}(1 - K)} \quad \ldots\ldots\ldots (1)$$

one obtains

$$t = \frac{1}{\frac{K}{t_0} + \frac{1 - K}{t_n}} \quad \ldots\ldots\ldots (2)$$

This form of the equation gives identical results for the time to any given total plastic strain and also is directly applicable to the calculation of fracture time. The elimination of the fracture strain from the formula gives calculated life values that fall within the same scatter band as those obtained by the authors' method. Equation 2 in effect adds the fraction of life lost at each stress, considering the relative durations, to obtain the total fraction of life lost per stress cycle; the reciprocal of this is the calculated life in cycles (or hours for a 1-hr cycle).

It seems proper to note that this same Eq 2 applies also to tests run at constant stress with varying temperature. If the temperature is varied in essentially square wave manner, the formula applies directly using t_o as the life at the higher temperature and t_n as the life at the low temperature. In the case of continuously varying temperature, the time-temperature curve can be approximated by short constant temperature sections at several temperatures. Each section will then have its term in Eq 2. Our program of rupture testing under conditions of varying temperature and constant stress is not complete but indicates that this type of calculation is applicable over a considerable area of conditions. It does, however, appear to yield optimistic results when the temperature range becomes large or the cycle frequency becomes high.

MR. M. J. MANJOINE.[3]—The influence of overstressing on the creep-rupture properties is of extreme importance to the design engineer. From the results presented by the authors the present methods of calculating accumulative creep and rupture damage can be checked. There are, however several points on which further information is necessary.

The authors state that the time pattern of overstressing has negligible effect as long as the time percentage of overstressing remains constant. They give the results of Fig. 3 of the paper to illustrate this point. It appears to me that there is a significant difference for the tests at 1200 F.

The second point is a question as to the sign of the discrepancies between the calculated times and the experimental results. Are the calculated times greater or less than those for the experimental results? From a rough calculation from the curves it appears as though the overstressing increases the rate of damage so that the time to a given strain or rupture is less than that calculated from the static load tests as suggested by the authors.

Finally, have the authors tried calculating the time to a given strain or strain for a given time by using a McVetty type law for the static curves?

MESSRS. G. J. GUARNIERI AND L. A. YERKOVICH (*authors' closure*).—It is of considerable value and interest to the authors to have the comments of those individuals who are closely associated with the day-to-day problems of selection and application of materials for jet aircraft service. Mr. Johnson, in particular, has summarized the simulated-service materials-testing situation and has emphasized the need for test programs, the results of which may be translated into actual service conditions.

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[3] Research Laboratories, Westinghouse Electric Corp., East Pittsburgh, Pa.

The precise overload conditions encountered in the operation of military turbojet aircraft are not known by the authors. Undoubtedly they are quite variable both in magnitude and pattern of occurrence. The test conditions used in the program described in the paper were selected with the objective of covering a range of the variables involved for the particular materials studied. The value of such data lies principally in establishing trends and generalizations which might serve as a guide to design engineers faced with the problem of determining allowable stress values for materials subjected to overload service conditions. It is true that such data can be used to best advantage only if the expected overload or at least maximum overload circumstances are known.

Both Mr. Manjoine and Mr. Johnson have interpreted the results of Table I and Fig. 3 to indicate that a significant effect is exerted on the overload creep-rupture properties by the time pattern of overload used. We do not feel that the differences noted are significant. The largest variations are found to occur at the 1200 F temperature level where stresses causing several per cent deformation on loading must be used in order to give reasonable amounts of creep in the several hundred hour time range. Thus the spread in any of the time-deformation plots is dependent upon the initial loading deformation which in thin sheet material may vary from specimen to specimen to the extent displayed by the curves of Fig. 3.

The desirability of transforming the equation for estimating overload creep and rupture times from static load data to the form suggested by Mr. Wilkes is recognized, since it provides a common method of calculation for both deformation and rupture conditions. The scatter band obtained from such calculations, using either form of the equation, overlaps both the plus and minus side of the experimental test results.

PREDICTION OF CREEP CURVES FROM STRESS-STRAIN DATA*

By Yoh-Han Pao[1] and Joseph Marin[1]

Synopsis

This paper develops a method for predicting tension creep-time relations for constant stresses from tensile stress-strain relations at various strain rates. The method is applied to test data obtained using plexiglas, and the agreement between actual and predicted creep-time curves was found to be good. The proposed procedure given in this paper differs from other "equations of state" procedures in considering the creep strains and creep rates and not the total strains and total strain rates when using the stress-strain relations for predicting the creep-time curves. This is equivalent to suggesting that a mechanical equation of state exists for creep strains and creep rates alone.

Many tension tests have shown that the shape of the stress-strain curve is influenced by the rate of strain. The extent of this influence depends upon the material considered. For some metallic materials, such as steel and aluminum alloys, and for room temperatures, the initial elastic part of the stress-strain curve is not influenced by the strain rate. On the other hand, for some materials, as for example, cellulose acetate, plexiglas, and other plastics, the rate of straining influences the shape of the entire stress-strain diagram. It is herein suggested that the foregoing influence of strain rate on the stress-strain curve is an indication that creep strains are responsible for the variations in the stress-strain relation. This seems reasonable, since for materials that do not creep in the elastic range the strain rate does not influence the stress-strain relation. For materials which creep and for low strain rates there is ample time for creep to take place and large strains result, while for high rates of strain relatively small strains result for equal stress values.

The method described in this paper is based on the foregoing considerations and appears to give good agreement between actual and predicted creep-time relations.

Zener and Hollomon (**1, 2**)[2] in proposing the idea of a mechanical equation of state for plastic strains of metals have also suggested a method for predicting creep-time relations from stress-strain data. Although they stated that the mechanical equation of state was proposed only for the plastic strains, no correction is made for elastic strains and elastic strain rates in the method. In other words, all strains are thought of as "plastic strains," and the "strain rate" of the stress-strain diagram becomes the "creep rate" of the creep-time relation.

Nadai (**3**) has also proposed a method very similar to that of Zener and Hollomon.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Department of Engineering Mechanics, The Pennsylvania State College, State College, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 957

To the author's knowledge, no successful prediction of creep-time curves from stress-strain data has been reported. On the other hand, the idea of the existence of a mechanical equation of state for plastic strains of metals has been shown to be incorrect in many cases (4, 5, 6). Findley (7) has tried to apply the Hollomon mechanical equation of state to predict creep-time relations of plastics from stress-strain data. He was not able to obtain satisfactory agreement between the predicted and actual creep-time relations.

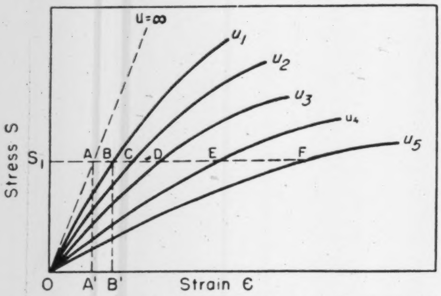


FIG. 1.—Typical Stress-Strain Curves Obtained from Constant Strain Rate Tests.

METHOD OF ANALYSIS IN PREDICTION OF CREEP CURVES FROM STRESS-STRAIN DATA

In the method proposed in this paper, a family of stress-strain curves obtained from constant strain rate tests of a plastic in tension are first represented in Fig. 1 for various strain rates u_1 to u_5. In Fig. 1, the higher the strain rates the greater are the slopes of the stress-strain curves. Test data also indicate that as the strain rate u increases, the stress-strain curve gradually approaches a straight line. It will, therefore, be assumed in this analysis that for an infinitely high rate of strain, the material does not have time to creep, and the stress-strain relation is represented by a straight line OA as shown in Fig. 1. For a strain rate u_1 the material, however, does have time to creep, and the total strain at the stress S_1 is OB'. The strain OB' is made up of $DA' + A'B'$ where $A'B' = AB$ and represents the creep strain that took place under a varying stress and in the time necessary to load the specimen from a stress value $S = 0$ to $S = S_1$.

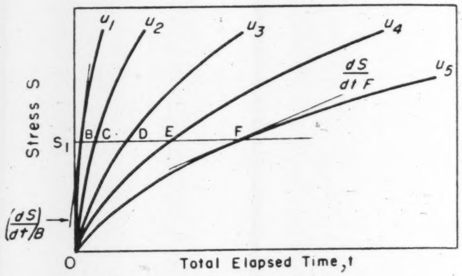


FIG. 2.—$S - t$ Curves.

At any time t the total strain ϵ_t is the sum of the elastic (ϵ_e) and creep (ϵ_c) strains, or

$$\epsilon_t = \epsilon_e + \epsilon_c \qquad (1)$$

Differentiating Eq 1 with respect to time,

$$\frac{d\epsilon_t}{dt} = \frac{d\epsilon_e}{dt} + \frac{d\epsilon_c}{dt} \qquad (2)$$

By Hooke's law $\epsilon_e = S/E$, where E is the modulus of elasticity, and $\frac{d\epsilon_t}{dt} = u$, the strain rate. Then, Eq 2 can be written

$$u = \frac{1}{E}\frac{dS}{dt} + \frac{d\epsilon_c}{dt} \qquad (2(a))$$

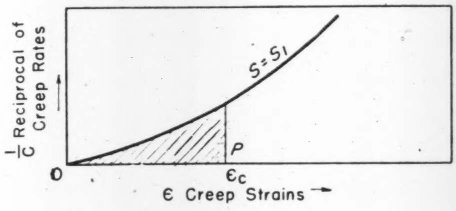
Equation 2(a) states that the resultant strain rate u is the sum of the rate of change of the elastic and creep strains or the sum of the elastic strain rate and creep strain rate. The creep strain rate is usually called the creep rate and will be so called in this paper.

To determine the creep-time curves for a constant stress from the stress-strain curves at various strain rates, as given in Fig. 1, the following method is proposed. For a point B on the u_1 curve of Fig. 1, the stress is S_1 and the total strain is OB', so that the total elapsed time in stressing from 0 to S_1 is $t_B = \overline{OB'}/u_1$. Total elapsed times can be determined in this way for other points on the u_1 curve. With this series of time values obtained from the u_1 curve, a stress-time relation can be plotted as shown in Fig. 2. Other stress-time relations can be similarly plotted using the various curves in Fig. 1. Returning to the u_1 curve of Fig. 2, the slope of the curve at a point B will be $(ds/dl)_B$ and by Eq 2(a), designating the creep rate $d\epsilon_c/dt$ by C_B,

$$u_1 = \frac{1}{E}\left(\frac{dS}{dt}\right)_B + C_B$$

or

$$C_B = u_1 - \frac{1}{E}\left(\frac{dS}{dt}\right)_B \text{.........(3)}$$



Area Under Curve $= t = \int_0^{\epsilon_0} \frac{d\epsilon_0}{\left(\frac{d\epsilon_c}{dt}\right)} =$

Time necessary for material to develop creep strain of ϵ_0 under stress S.

FIG. 3.—$\frac{1}{C} - \epsilon_c$ Curves.

As written, Eq 3 gives the creep rate for a stress S_1 and for a creep strain equal to $\overline{AB}$ in Fig. 1. It should be noted that this method assumes a definite value of creep rate for each stress and corresponding creep strain. This assumption is implied when a mechanical equation of state for creep is used. It also is the assumption used in the strain-hardening law for creep. For points C, D, E, and F in Figs. 1 and 2 at a stress S_1 the corresponding values of creep rates and creep strains can be found. It is therefore possible to determine from Figs. 1 and

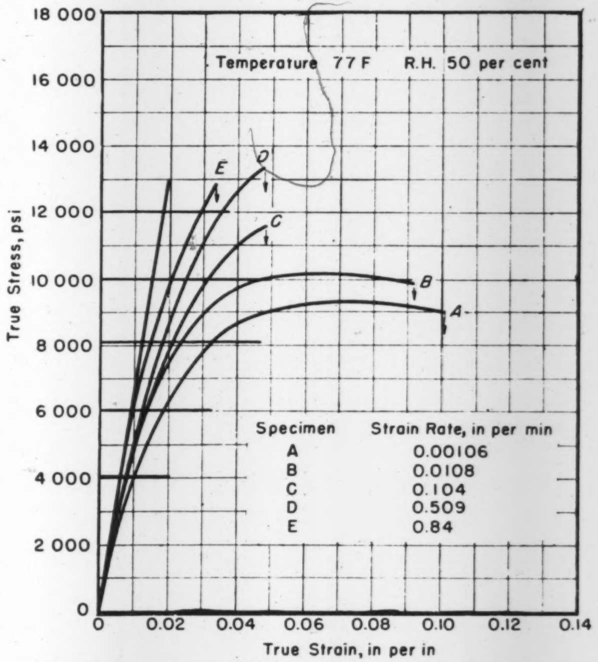


FIG. 4.—True Stress True Strain Curves for Plexiglas II (Tension).

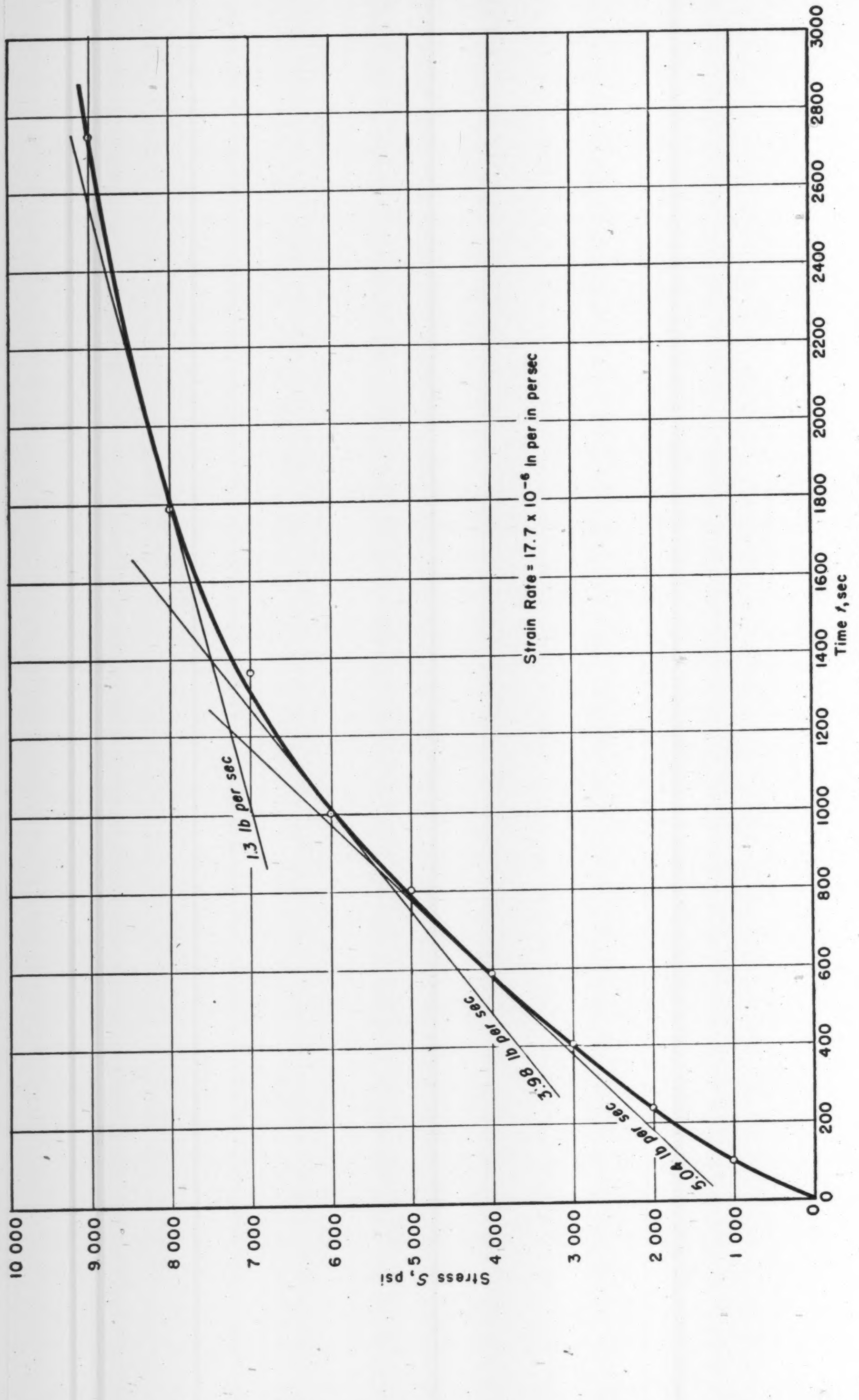


FIG. 5.—$S - t$ Curve for Plexiglas II.

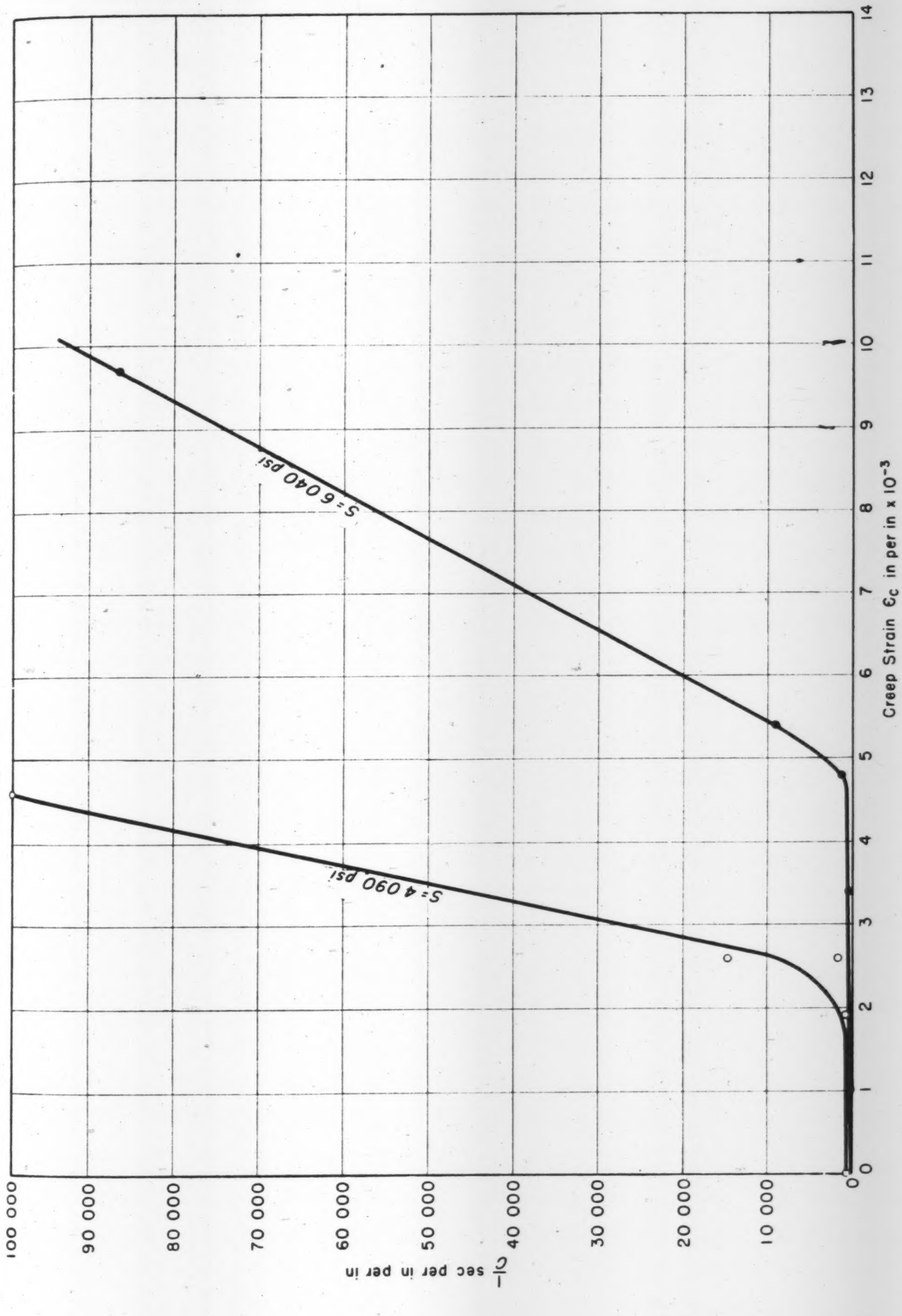


FIG. 6.—$\frac{1}{C} - \epsilon_c$ Curve for Plexiglas II.

2, for each stress value selected, a series of creep strain and corresponding creep rate values.

From the creep rate values the reciprocal of the creep rates ($1/C$) can be found and a graph representing the variation between $1/C$ and ϵ_c, the creep strain, can be plotted for each stress value, as shown in Fig. 3 for stress S_1. Then, in Fig. 3, if $\overline{OP} = (\epsilon_c)_B$, the time required for the material to creep at a constant stress S_1 to a creep strain $(\epsilon_c)_B$ (equal to $\overline{AB}$ in Fig. 1) is represented by the area under the $\frac{1}{C} - \epsilon_c$ curve in Fig. 3, since the time is

$$t = \int dt = \int \frac{d\epsilon_c}{(d\epsilon_c/dt)} = \int_0^{\epsilon_0} \frac{1}{C}\, d\epsilon_c \ldots (4)$$

For a series of values of the creep strain, areas under the curve in Fig. 3 will determine a series of time values, and a creep-time relation can be plotted for the stress S_1. For other stress values, the foregoing procedure can be applied for the determination of other creep-time curves.

APPLICATION OF METHOD

The method developed above was applied to data obtained using plexiglas II manufactured by Rohm & Haas and designated as B287-1. Figure 4 gives the constant strain rate stress-strain tension diagrams for this material. Following the procedure explained above, the stress-time relations were obtained. A typical stress-time curve for the strain rate of 17.7×10^{-6} in./in./sec. is shown in Fig. 5. Using Fig. 4 and the stress-time relations similar to that shown in Fig. 5, the $1/C - \epsilon_c$ curves were obtained. Two typical $1/C - \epsilon_c$ curves are shown in Fig. 6. By numerical integration, the areas under the curves in Fig. 6 were obtained. These areas represent the

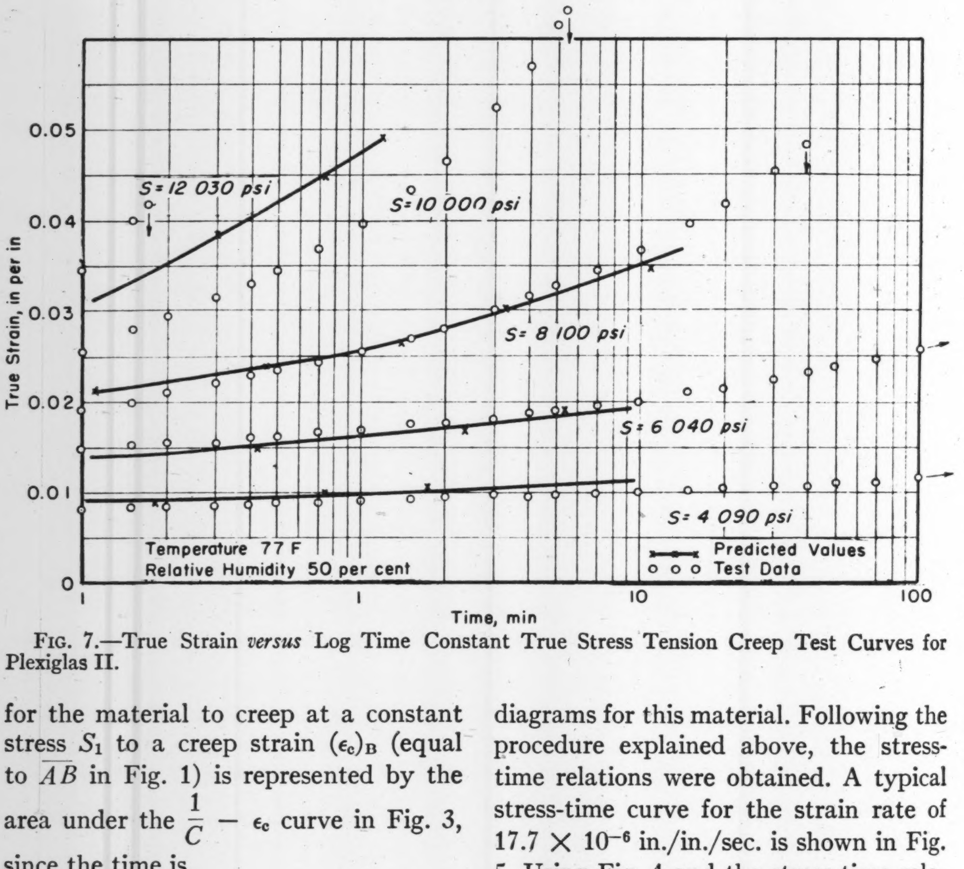


FIG. 7.—True Strain *versus* Log Time Constant True Stress Tension Creep Test Curves for Plexiglas II.

times for each strain and stress value. The same procedure was applied to the other $1/C - \epsilon_c$ curves not shown in Fig. 6. A plot of these results gives the creep-time relations shown in Fig. 7. In plotting the creep-time relations, the elastic strains were also included so that the results could be compared as indicated in Fig. 7 with the actual creep-time curves for which the elastic strains are included. The elastic strain values were taken as S/E, where the value of E is obtained from the slope of the straight line for a value of $u = \infty$. This value of E is also used for determination of creep rates in Eq 3.

A comparison of the actual and predicted creep-time relations as given in Fig. 7 shows that except for the higher stress value of 10,000 psi, the agreement is good.

CONCLUSIONS

This paper develops a method for predicting creep-time relations for constant stress based on stress-strain curves for various strain rates. For the material and test results considered, the agreement between the theoretical and actual creep-time relations was found to be good. The essential difference between the foregoing method and formerly proposed mechanical equation of state procedures is that this method applies the mechanical equation of state to the creep strains and creep rates only rather than to the entire strain and total strain rates.

Graphical and numerical procedures have been used in this analysis in order that no actual "equation" of state need be formulated. It is felt that the exact form of the "equation" is relatively unimportant compared to the basic idea that such a general relation does exist.

Acknowledgment:

This paper represents a part of an investigation conducted under the sponsorship of the Research Corp. The authors appreciate the financial assistance given by Research Corp., which made this study possible. They also wish to thank Prof. A. H. G. Dietz for supplying test data used in the analysis given.

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(3) A. Nadai, "The Influence of Time upon Creep—The Hyperbolic Sine Creep Law," *Stephen Timoshenko 60th Anniversary Volume*, The Macmillan Co., New York, N. Y., pp. 150–170, (1938).

(4) E. Orowan, "The Creep of Metals," *Journal*, West of Scotland Iron and Steel Inst., Vol. 54, February, 1947.

(5) J. E. Dorn, A. Goldberg and T. E. Tietz, "The Effect of Thermal-Mechanical History on the Strain Hardening of Metals," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 180 (1949), *Metals Technology*, Sept., 1948, TP 2445.

(6) T. E. Tietz and J. E. Dorn, "The Effect of Strain Histories on the Work Hardening of Metals," *Transactions*, Am. Soc. Metals, 41A (1949).

(7) W. N. Findley, "The Mechanical Equation of State with Special Attention to the Creep of Plastics," *Journal*, Soc. Plastics Engrs., Vol. 6, No. 10, Dec., 1950.

DISCUSSION

Mr. J. D. Cummings.[1]—This work is very interesting as we have stress-strain data on polyethylene to which it could be applied. We have unloading data at about 1000 and 10,000 hr. The amount of permanent strain was relatively small. Our data is given in a paper on the Creep of Polyethylene by G. R. Gohn, J. D. Cummings and W. C. Ellis presented before the Society in 1949.[2]

Mr. C. R. Stock.[3]—Will the recovery curve approach the horizontal fairly rapidly? Are there not situations where it takes an extremely long time to determine the true permanent set of the material?

Mr. Yoh-Han Pao (*author*).—Near the end of my presentation of our paper, I said that the results of our work show that the deviation of the stress-strain curve from the linear is principally due to short-time creep or transient creep. Although steady rate creep is also present, its magnitude is so small in comparison that there is very little possibility of measuring it. I suggested then that a good way of obtaining a value of the steady creep rate from a relatively short time test would be to conduct a creep and creep recovery test. The creep strain that is not recovered is considered to be steady rate creep strain and, when divided by the length of time of the creep test, would give a value of the steady creep rate. This value of the steady creep rate or minimum creep rate could then be considered to be valid for long time applications. I believe the remarks of both Mr. Cummings and Mr. Stock are concerned with this suggestion of mine.

As far as Mr. Cummings' comment is concerned, I wish to say that we would indeed welcome experimental checks of this proposed method of obtaining the minimum creep rate.

With regard to Mr. Stock's comment, I would like to point out that if the creep test is carried out for 100 hr, the recovery should also be for a period of at least 100 hr. Under those conditions, the recovery curve will approach, we hope, a horizontal. It does, at least, for Plexiglas.

Mr. Stock.—That was the implication I was wondering about. In other words, you are saying that in most instances where the test has been used an equivalent recovery time seems to bring the curve back to a horizontal asymptote.

Mr. Pao.—I think that is true of many other tests reported.

Mr. W. N. Findley.[4]—The authors state that in my study of the mechanical equation of state[5] I was unable to obtain satisfactory agreement between actual creep-time relations and those predicted from stress-strain data. I should like to correct that impression. At the time my paper was written the only data available which included creep tests and stress-strain curves at several strain rates was cellulose acetate. The range of strain rates and creep rates available did not overlap; it was only possible to establish that the creep rate and strain rate were of the same order of magnitude at the same stress and strain. The agreement was good within the precision available.

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[1] Member of Technical Staff, Bell Telephone Laboratories, Murray Hill, N. J.

[2] "The Creep Characteristics of Compression Molded Polyethylene," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 1139 (1949).

[3] Senior Group Leader, American Cyanamid Co., Stamford, Conn.

[4] Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[5] W. N. Findley, "The Mechanical Equation of State with Special Attention to Creep of Plastics," *Journal*, Soc. Plastics Engrs., Vol. 6, No. 10, p. 13 (1950).

Also in the paper cited[5] a mathematical expression, proposed earlier[6] to describe creep test data for a canvas laminate, was used to derive a stress-strain equation for tests at constant strain rate. The agreement between the prediction of these equations and test data was excellent as shown in the accompanying Fig. 8.

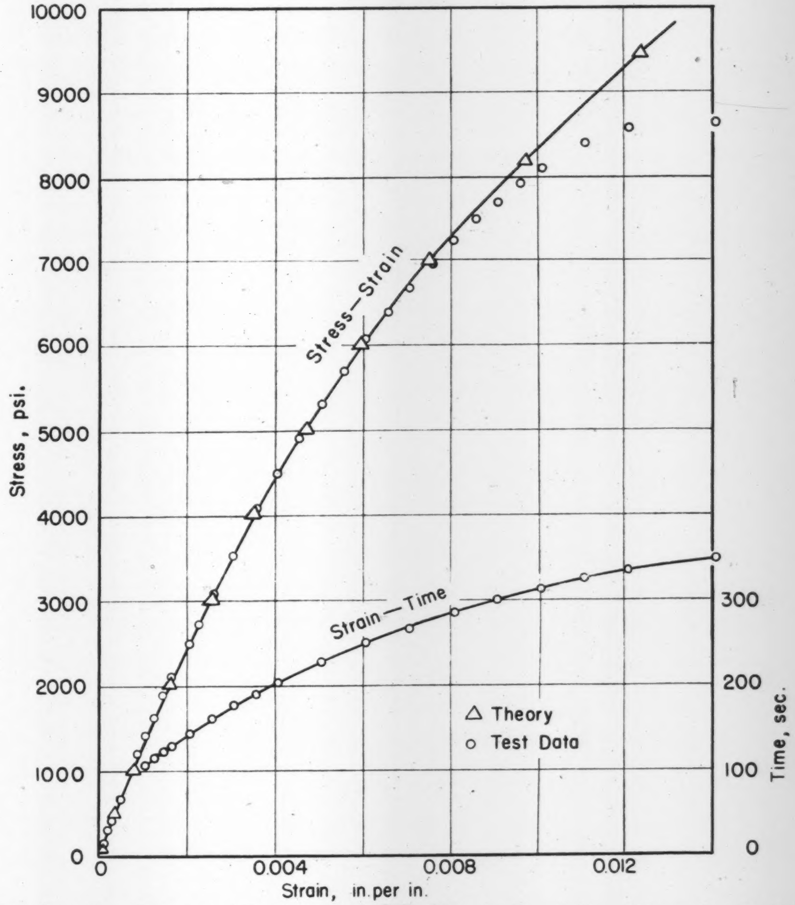

FIG. 8.—Relation Between Actual Stress-Strain Data in Tension and Equation Derived from Creep Data.

It was interesting to note that the authors have employed an expression for deriving creep behavior from tension tests which is essentially the same as that included in the original manuscript of the paper referred to above.[5] This material was deleted from the published condensation of that paper but was included in a paper presented a year ago.[7] Because the available data were inadequate to obtain the necessary precision the graphical procedure mentioned in the paper was not employed. Instead the mathematical procedure mentioned above was used to derive stress-strain relations from creep data.

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[6] William N. Findley, "Creep Characteristics of Plastics," Symposium on Plastics, Am. Soc. Testing Mats. p. 118, (1944). (Issued as separate publication *STP No. 59.*)

The authors have made an observation which I should like to emphasize. That is, one should not be too optimistic regarding the applicability of a mechanical equation of state to plastics, or any other material. As indicated in my paper of a year ago,[7] there are conditions under which the mechanical equation of state does not apply. Hence, in order to make use of this relation we must determine the conditions under which it is applicable.

These conditions seem to be that the structure of the material must not change. Since the structure of most materials does change under many test conditions, it seems desirable to determine what the creep and other behaviors are for a material of constant structure and then determine the changes which occur in the constants of the equations when the structure changes.

MR. PAO.—There can be no possibility of any similarity between the method used by the authors and that used by Mr. Findley. In Mr. Findley's paper, the method used is based on the procedure suggested by Zener and Hollomon in which the mechanical equation of state is applied to stress, total strain, and total strain rate. In this paper, we specifically show how our method differs from that used by Zener and Hollomon and by Findley. We assume that a mechanical equation of state holds only for the stress, the transient creep strain, and the transient creep rate. Elastic strains are treated separately and steady rate creep strains are neglected in short time applications. All this means, of course, that we are quite aware of the fact that the mechanical equation of state is not to be applied haphazardly to strains which may be made up of different components obeying different physical laws and we are happy that Mr. Findley agrees with us in this respect.

A graphical procedure was used in our paper in order to avoid controversy concerning empirical mathematical expressions. The only expressions used in our paper are mathematical identities used to explain the graphical procedure. For example, in Eq 4 time is given as

$$t = \int dt = \int \frac{t}{\left(\frac{de}{dt}\right)} dE = \int \frac{1}{c}\, de$$

I doubt that anyone can seriously lay claim to having been the first to formulate these identities.

MR. H. M. QUACKENBOS, JR.[8] (*by letter*)—This paper is interesting in its academic and theoretical aspects. It is proved that the stress-strain curve for Plexiglas deviates from the linear because of creep. Further it is shown that short-time creep curves can be predicted from stress-strain curves.

Had the authors stopped here all would have been well. Unfortunately, they encourage the impression that the findings have an immediate practical use. The word "prediction" occurs in the title. In engineering circles this word suggests a labor-saving procedure. Thus we begin reading with the hope that we can cut out several hundred or thousand hours of creep-testing and instead can make a few calculations from tensile stress-strain curves. The synopsis and most of the contents buoy up this hope of practicality. But on page 957 we are disappointed. It appears that (*a*) the creep curves are predicted not for 10 months or even 10 days but for 10 min, (*b*) these predictions for 10 mins are made from tension tests that lasted as long as 100 min (curve *A*, Fig. 4), and (*c*) the stresses are far above those to which Plexiglas would be subjected by any engineer in his right mind.

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[7] W. N. Findley, "Derivation of a Stress-Strain Equation from Creep Data for Plastics," First National Congress of Applied Mechanics, Paper No. 108, June 1951.

[8] Bakelite Co., Bound Brook, N. J.

We believe that the unfortunate, if unintentional, bias towards practicality can only leave a bad impression with the serious reader considering the use of plastics.

MR. PAO.—From Mr. Quackenbos' comments on our paper and his choice of words to describe his reaction, I cannot help feeling that he is in this case a victim of his own expectations. His interest in long-time creep tests evidently causes him to be disappointed in any creep test that is not of long duration. He should be aware however that there are many engineering applications where extremely short time creep strains are of great importance.

Furthermore I cannot agree that even in engineering circles the word *prediction* must necessarily imply a labor-saving procedure. I think that prediction of actual phenomena is often used as a means of providing an experimental check of a new theory. Quite often the procedure of prediction is more tedious than the measurement of the phenomena predicted.

The results of our work show that the deviation of the stress-strain curve from the linear is principally due to short-time creep or transient creep. Although creep strains of the nature associated with the minimum rate creep are present, it is extremely difficult to isolate them and measure them accurately. It must be concluded therefore that it will be practically impossible to predict long-time creep curves from stress-strain data. Under the circumstances, a negative result of this type is not devoid of practical significance. The results of this study also indicate that the usual offset method of determining a yield strength is clearly inapplicable to plastic materials.

To my mind, the serious reader considering the use of plastics does not necessarily limit his interest to long-time creep data. Having made no exaggerated claims in our work, I fail to see why mere presentation of our results should necessarily leave the serious reader with a bad impression.

EXPLORATORY INVESTIGATION OF HIGH-TEMPERATURE SHEET MATERIALS*

By D. Preston[1]

Synopsis

The purpose of this project was to determine the high temperature mechanical properties of several materials commercially available in sheet form. The materials investigated included three iron-base strain hardening type alloys, three iron-base age hardening type alloys, and three cobalt-base alloys which are used in the annealed condition. Micro-structures are discussed and creep, stress rupture, and short-time tension and yield data are presented for these alloys from room temperature to 1800 F.

Current advances in the design of aircraft gas turbines have placed great emphasis on the development and application of sheet metal structural parts. Metallurgical and design problems have long been encountered in the combustion and exhaust systems of the conventional engine. With the recent innovation of the reheat system and the advent of the hollow fabricated bucket, the performance of sheet metal parts may well be the limiting factor in the service life of an engine.

The great percentage of high-temperature data has been recorded on materials in bar form. In view of the increasing need for similar information on sheet material, this program was sponsored by the Aviation Panel of the ASTM-ASME Joint Committee on Effects of Temperature on Properties of Metals under Project AP-2.

The shortcoming of evaluating materials for use in aircraft gas turbines from limited strength data is realized. It is well known that consideration must necessarily be given to fabrication, corrosion, and thermal characteristics, and that prior to acceptance a material must undergo repeated and prolonged service testing in the turbine unit itself. When sufficient conditions of operation have been known, however, laboratory tests have proven to be reliable indications of performance and serve to eliminate many time-consuming engine tests. The purpose of this program, then, is to supply the aircraft industry with a few mechanical properties of a representative group of high temperature materials.

In determining the life of any part under continued high temperature loading, one property of greatest significance is stress to cause rupture at given time and temperature. In the operation of aircraft gas turbines, however, severe localized overheating or overstressing may occur for short durations. In the interest of safety, therefore, designs must account for short-time strengths of alloys at temperatures slightly higher than expected operating levels, as well as stress rupture strengths at the expected operating temperature level.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Metallurgical Engineer, Thomson Laboratory, General Electric Co., Lynn, Mass.

Nine alloys were studied metallographically and investigated for creep, stress rupture, and tensile and yield properties at temperature ranging from room to 1800 F. Fatigue and thermal shock data are also being determined on these alloys and will be reported at a later date.

PROCEDURE

Metallography:

Preliminary metallographic studies were made in order to identify the constituents present in the various microstructures. Comments resulted from a combined optical microscopy and X-ray diffraction technique.[2] The specimens were observed in the heat-treated condition prior to mechanical testing and photomicrographs of 500× magnification are included in this paper.

TABLE I.—CHEMICAL COMPOSITIONS OF SHEET ALLOYS TESTED.

Alloy	C	Cr	Ni	Mo	Co	Cb	Ti	Si	S	P	Mn	W	Fe	Others
Timken	0.09	15.84	25.25	6.40	...	...	...	0.42	0.015	0.021	1.76	...	bal.	N_2 = 0.167
19-9-DL annealed	0.27	19.28	9.99	1.35	...	0.50	0.30	0.41	0.009	0.017	1.22	1.43	bal.	...
19-9-DL cold rolled	0.29	18.65	8.97	1.34	...	0.54	0.30	0.54	0.010	0.019	1.15	1.47	bal.	...
H.S. No. 88	0.07	12.62	15.04	2.42	...	...	0.50	0.52	0.006	0.013	1.40	0.84	bal.	B = 0.14
Discalloy 24	0.036	13.50	26.20	3.91	...	...	1.61	1.00	...	...	1.38	...	bal.	Al = 0.11
Tinidur 1650	0.04	14.70	26.10	...	...	...	2.26	0.73	0.015	0.020	1.00	...	bal.	Al = 0.15
Tinidur 1875	0.04	14.70	26.10	...	...	...	2.26	0.73	0.015	0.020	1.00	...	bal.	Al = 0.15
A-286	0.07	15.80	26.10	1.39	...	...	1.59	1.00	0.010	0.014	1.62	...	bal.	Al = 0.14 V = 0.26
L-605	0.08	21.11	10.84	...	bal.	...	...	0.61	0.006	0.010	1.64	15.54	1.60	N_2 = 0.03
V-36	0.27	24.70	19.29	4.39	bal.	1.71	...	0.18	0.017	0.013	0.86	2.31	1.87	...
WF-31	0.156	20.34	9.93	2.61	bal.	...	1.03	0.42	0.016	0.009	1.42	10.69	4.13	...

TABLE II.—EFFECT OF TEMPERATURE ON TENSILE STRENGTH.

Alloy	Room	750 F	1000 F	1200 F	1350 F	1500 F	1650 F	1800 F
Timken	124 800	109 600	103 700	90 500	67 900	48 075	31 700	20 183
19-9-DL annealed	105 200	91 650	83 450	59 750	38 900	22 000	14 583	10 700
19-9-DL cold rolled	129 550	....	91 900	72 090	....	26 805	....	9 595
H.S. No. 88	101 750	87 450	82 725	71 850	59 700	45 800	33 650	17 200
Discalloy 24	142 500	125 200	119 350	95 800	71 300	33 030	18 800	11 175
Tinidur 1650	149 500	135 750	131 150	106 000	81 850	42 500	19 025	13 025
Tinidur 1875	147 350	134 500	127 300	106 000	78 600	40 900	16 116	10 775
A-286	143 400	....	119 000	95 000	72 600	27 600	....	....
L-605	160 700	138 000	130 550	94 000	83 750	55 250	34 200	29 175
V-36	144 050	135 250	125 300	91 100	69 700	51 400	35 250	28 350
WF-31	148 250	122 533	114 100	94 850	77 900	56 050	32 750	27 750

Short-Time Tension:

Test specimens 1 by 21 in. were cut from 0.062-in. sheet or strip with their longitudinal axis parallel to the direction of rolling. In order to minimize the effects of work-hardening in the preparation of the test section, 0.5 by 2 in. specimens were milled to 0.055-in. oversize, ground to plus 0.005-in., and polished to size with a grit-filled buffing wheel. Samples were held in a vise grip at testing temperature for 30 to 45 min before being pulled at a crosshead speed of 0.050 in. to 0.060 in. per in. of gage length per min. Temperatures are within ±5 F of indicated temperatures except at 1800 F, at which temperature a variation of +0, −50 F exists.

Yield strength data for samples tested at 1500 F and below were obtained by using a (250 to 1 or 500 to 1) extensometer attached directly to the gage length of specimens. Yield point data for samples tested above 1500 F were obtained by using a (50 to 1 or 100 to 1) extensometer that measured the distance between crossheads. This change was necessary because the extensometer, which was attached directly to the specimen, could not be used above 1500 F. Two samples were tested at each temperature, and the average values are summarized in Tables II, III, IV, and V.

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[2] H. J. Beattie and F. L. Ver Snyder, Microconstituents in High Temperature Alloys, Submitted to American Society for Metals for possible publication.

TABLE III.—EFFECT OF TEMPERATURE ON ELONGATION.

Alloy	Room	750 F	1000 F	1200 F	1350 F	1500 F	1650 F	1800 F
Timken	25.0	23.0	28.0	19.5	22.0	31.5	30.5	38.0
19-9-DL annealed	43.0	22.0	21.0	32.0	49.0	70.5	80.0	60.3
19-9-DL cold rolled	22.0	...	8.5	10.0	...	37.0	...	69.0
H.S. No. 88	23.0	14.5	14.0	15.5	18.0	16.0	26.0	26.5
Discalloy 24	22.5	17.0	14.5	15.0	17.5	56.0	84.5	81.5
Tinidur 1650	19.0	12.0	9.75	4.5	3.25	9.0	55.5	61.0
Tinidur 1875	23.5	15.5	14.0	6.0	6.0	18.5	82.5	74.0
A-286	22.0	...	17.0	13.0	13.0	15.0	...	...
L-605	47.0	47.0	40.0	29.0	11.0	16.0	30.0	37.0
V-36	55.0	62.0	47.0	48.0	12.0	8.0	12.0	15.0
WF-31	60.0	59.0	43.0	17.0	38.0	14.0	21.0	24.0

TABLE IV.—EFFECT OF TEMPERATURE ON 0.0002 IN. PER IN. YIELD STRENGTH.

Alloy	Room	750 F	1000 F	1200 F	1350 F	1500 F	1650 F	1800 F
Timken	100 550	73 625	70 000	60 800	46 525	34 200	22 250	16 375
19-9-DL annealed	36 050	30 200	28 800	24 400	20 550	13 100	12 700	6 000
19-9-DL cold rolled	91 150	...	66 680	52 860	...	10 380	...	...
H.S. No. 88	78 275	62 000	58 600	50 600	44 425	34 625	31 550	15 750
Discalloy 24	75 625	67 950	66 000	65 250	59 750	26 400	17 400	10 225
Tinidur 1650	98 400	94 750	92 000	86 900	63 400	33 775	17 660	10 825
Tinidur 1875	94 875	80 300	79 800	76 100	59 875	29 100	13 875	9 025
A-286	91 800	...	72 600	69 400	59 800	21 350	...	...
L-605	60 950	47 450	51 900	53 060	48 250	39 800	27 600	25 775
V-36	51 400	34 975	36 200	32 450	32 400	33 200	30 650	23 975
WF-31	53 900	40 750	44 950	46 100	43 250	42 450	20 250	23 800

TABLE V.—EFFECT OF TEMPERATURE ON 0.002 IN. PER IN. YIELD STRENGTH.

Alloy	Room	750 F	1000 F	1200 F	1350 F	1500 F	1650 F	1800 F
Timken	104 300	79 500	73 450	67 450	56 900	43 100	28 350	18 325
19-9-DL annealed	49 900	42 900	37 500	33 000	26 400	17 400	13 500	7 600
19-9-DL cold rolled	108 350	...	81 887	65 255	...	16 957	...	...
H.S. No. 88	90 200	74 600	70 900	67 350	56 200	43 750	33 350	17 100
Discalloy 24	91 200	82 150	79 700	77 500	67 350	30 200	18 275	10 825
Tinidur 1650	115 900	109 350	105 150	101 400	78 125	40 650	18 850	11 775
Tinidur 1875	108 850	98 500	96 100	94 200	73 700	39 250	14 675	10 150
A-286	104 800	...	89 100	82 200	66 900	22 420	...	...
L-605	85 800	55 900	53 900	54 900	51 300	44 850	31 900	27 475
V-36	66 800	41 700	40 350	37 550	39 300	37 900	32 700	26 650
WF-31	76 250	48 150	48 100	47 500	45 250	46 050	23 800	26 150

Creep and Stress Rupture:

Creep and stress rupture specimens were prepared in the same manner as described under *Short-Time Tension*. All creep and rupture tests were made in tubular electric resistance furnaces in which the temperature was maintained within ±5 F of the nominal value over the gage length of the specimen. Specimens were gripped by a pin in the cool end of the strip and were held in the furnace approximately $\frac{1}{2}$ hr before applying the load. Creep measurements were obtained by the use of Schaevitz linear differential transformers mounted on extensometer rods clamped to the top and bottom of the 2-in. gage length of the specimen. The transformers are connected in a null balance system which actuates a dial gage calibrated in 0.0001-in. intervals. The over-all accuracy of the strain measuring system is better than

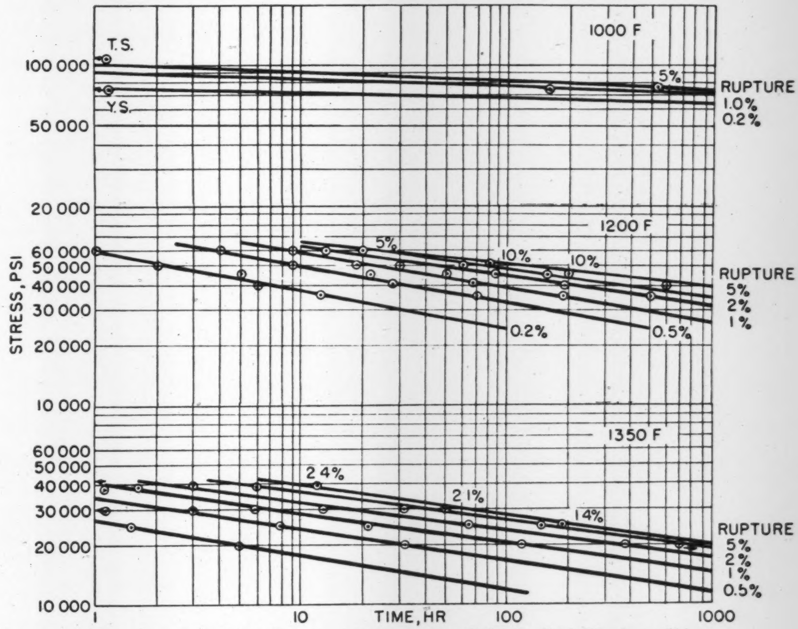

FIG. 1.—Standard Rupture Curves for Cold-Rolled Timken Sheet.

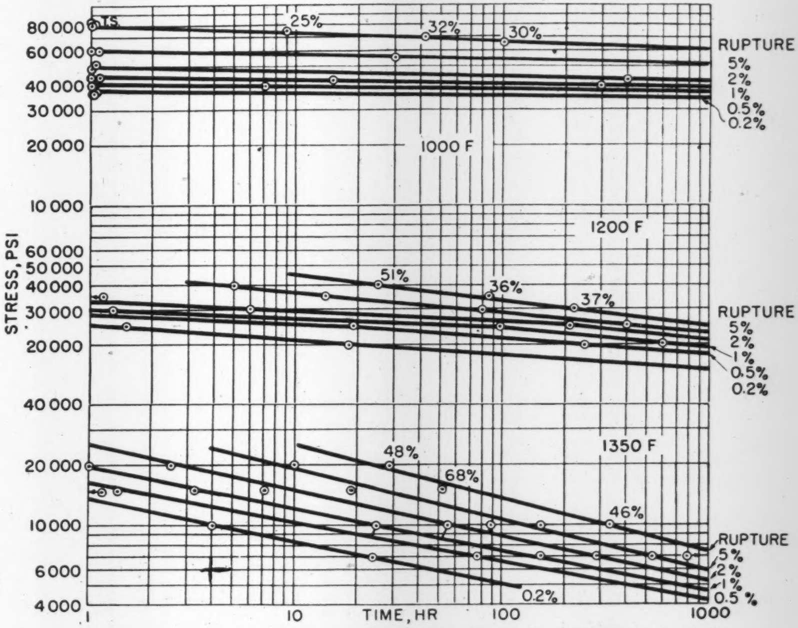

FIG. 2.—Standard Rupture Curves for Annealed 19-9-DL Sheet.

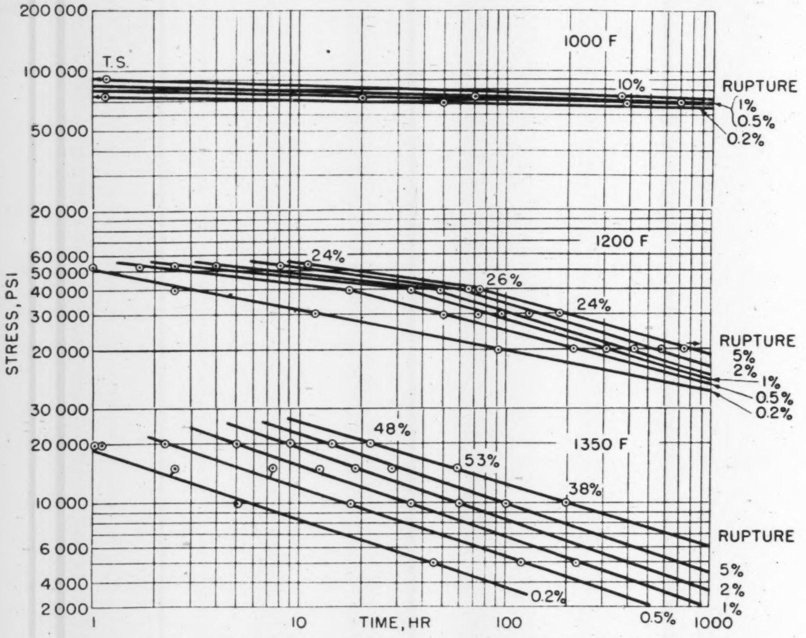

Fig. 3.—Standard Rupture Curves for Cold-Rolled 19-9-DL Sheet.

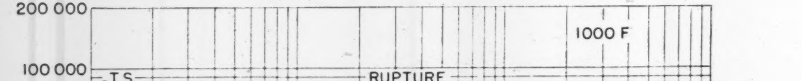

Fig. 4.—Standard Rupture Curves for Hot-Cold Rolled H.S. No. 88 Sheet.

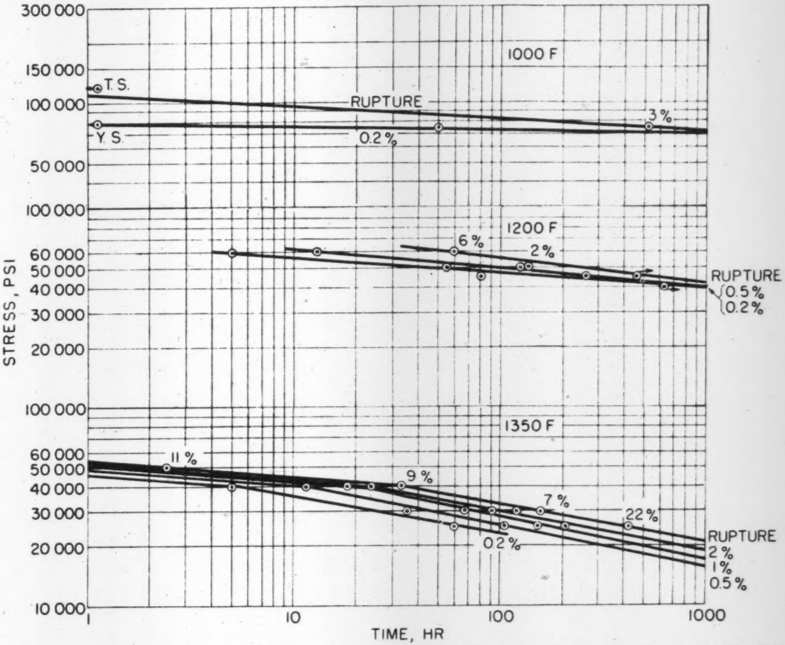

FIG. 5.—Standard Rupture Curves for Discalloy 24 Sheet Solution Treated (Aged).

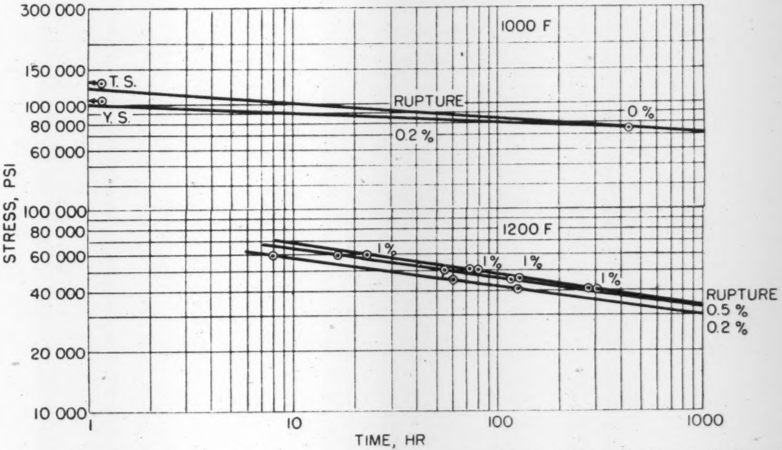

FIG. 6.—Standard Rupture Curves for 1650 F Tinidur Sheet Solution Treated (Aged).

±0.0005 in. per in. or ±0.05 per cent creep. The reported creep values represent total plastic strain and do not include elastic strain.

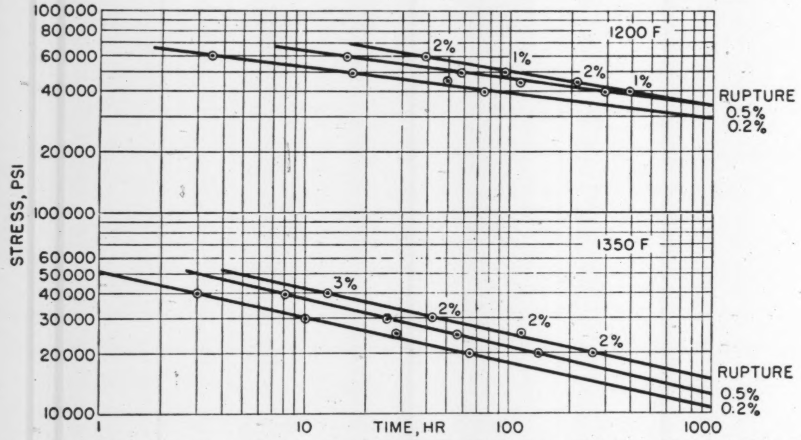

FIG. 7.—Standard Rupture Curves for 1875 F Tinidur Sheet Solution Treated (Aged).

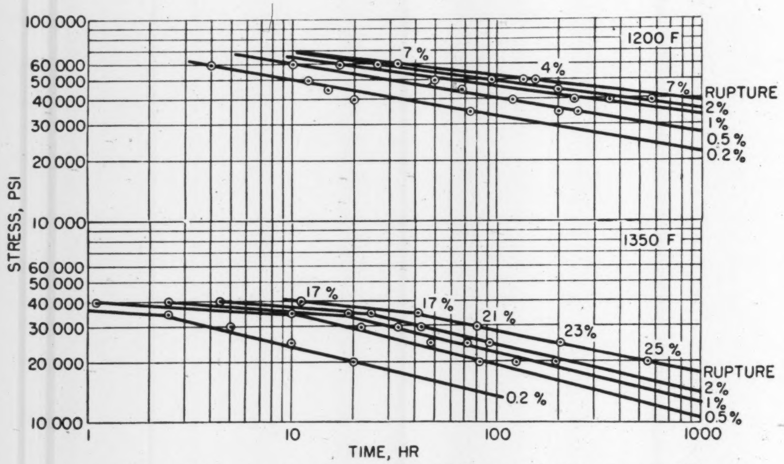

FIG. 8.—Standard Rupture Curves for A-286 Sheet Solution Treated (Aged).

Creep and stress rupture data are plotted in the conventional manner of log stress *versus* log time and are shown in Figs. 1 to 11. Numbers adjacent to the rupture points represent the total elongation at failure (2 in. measured length). Figures 13 to 23 illustrate master rupture curves on which the same creep and rupture points are plotted by use of a time-temperature relationship, $T(20 + \log t) \times 10^{-3}$, described by Miller and Larson.[3] (T = temperature in degrees absolute, t = time in hours). This allows the presentation of creep and rupture data of an alloy at any combination of time and temperature on a single master curve and facilitates comparison with other alloys. Figure 12 illustrates the conversion of temperature and time to various parameter readings.

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[3] F. R. Larson and J. Miller, "A Time-Temperature Relationship for Rupture and Creep Stresses," presented at Nov., 1951, meeting of Am. Soc. Mechanical Engrs.

MATERIALS

The chemical compositions of the alloys selected for this investigation are shown in Table I. This group represents three iron-base alloys which obtain their high temperature properties from strain hardening (Timken, 19-9-DL, H.S. No. 88), three iron-base alloys which obtain their high temperature properties from precipitation hardening (Discalloy 24, Tinidur, A-286), and three cobalt base alloys which are used in the fully annealed condition (V-36, L-605, WF-31). With the exception of 19-9-DL, tests were confined to one typical analysis of each alloy and heat to heat variations are not within the scope of this paper. The heat treatments used were those recommended by the vendor.

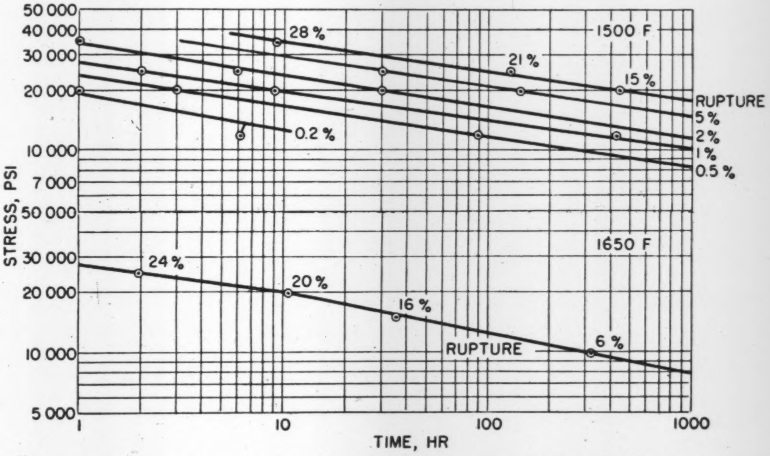

FIG. 9.—Standard Rupture Curves for Annealed L-605 Sheet.

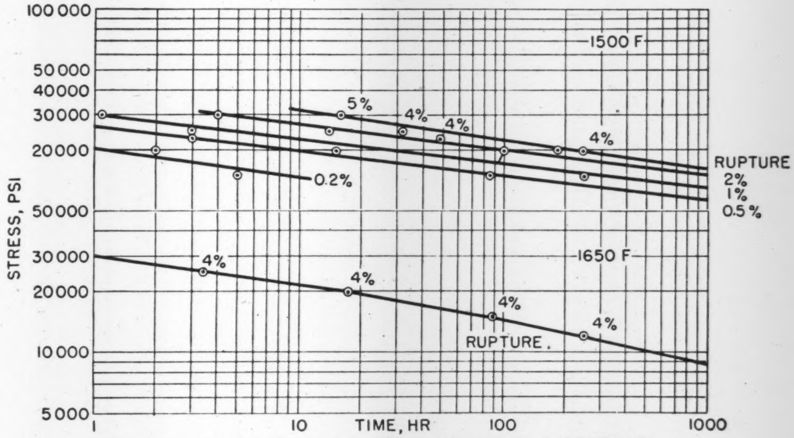

FIG. 10.—Standard Rupture Curves for Annealed V-36 Sheet.

Timken 16-25-6 (Fig. 24):

This material was melted and forged by the Timken Roller Bearing Co., Steel and Tube Div., and was rolled to sheet

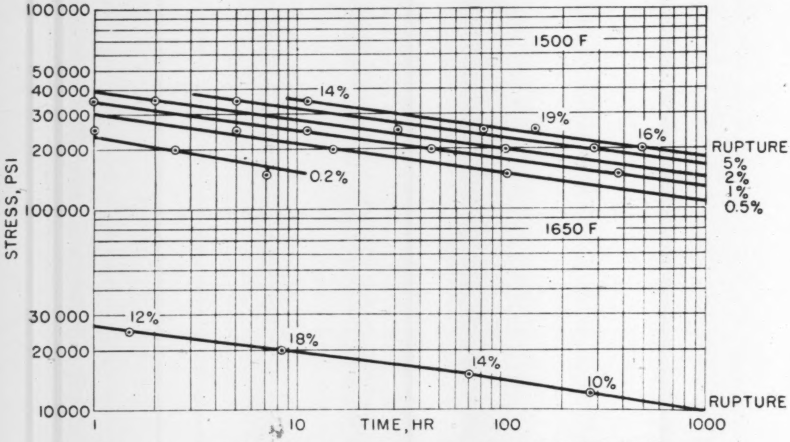

FIG. 11.—Standard Rupture Curves for Annealed WF-31 Sheet.

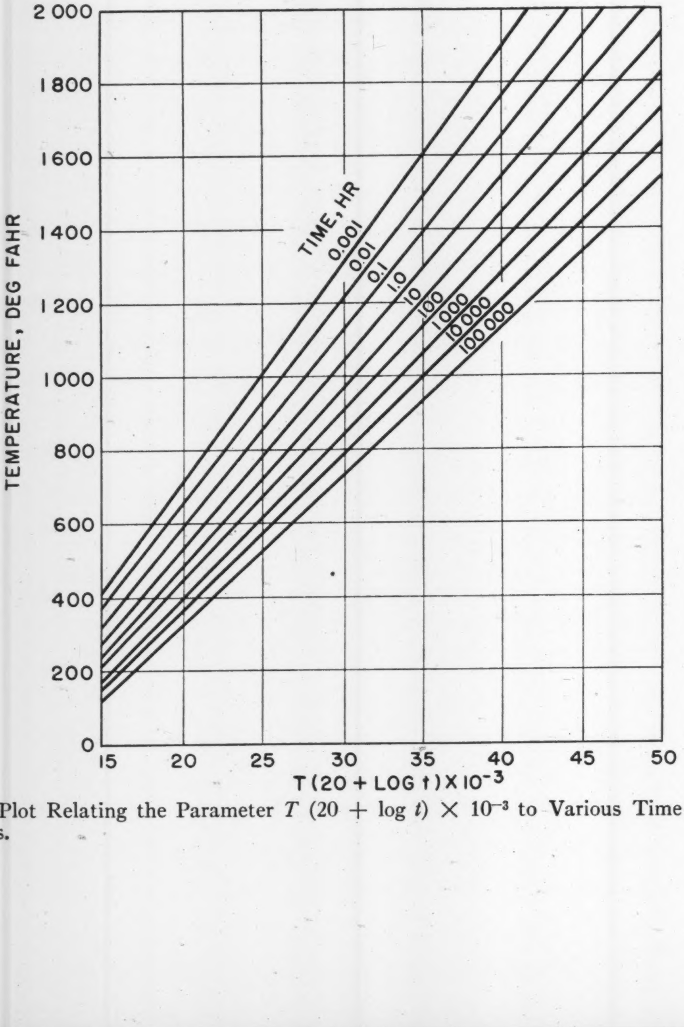

FIG. 12.—Plot Relating the Parameter $T\ (20 + \log t) \times 10^{-3}$ to Various Time-Temperature Combinations.

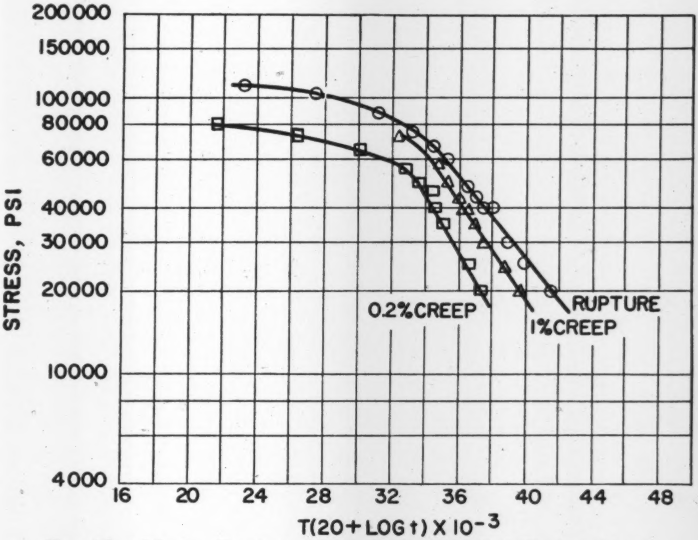

FIG. 13.—Master Rupture Curve for Cold-Rolled Timken Sheet.

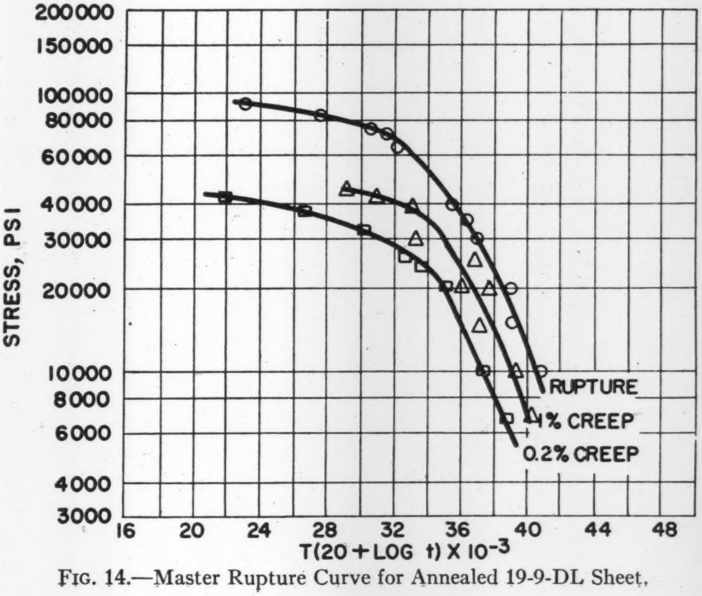

FIG. 14.—Master Rupture Curve for Annealed 19-9-DL Sheet.

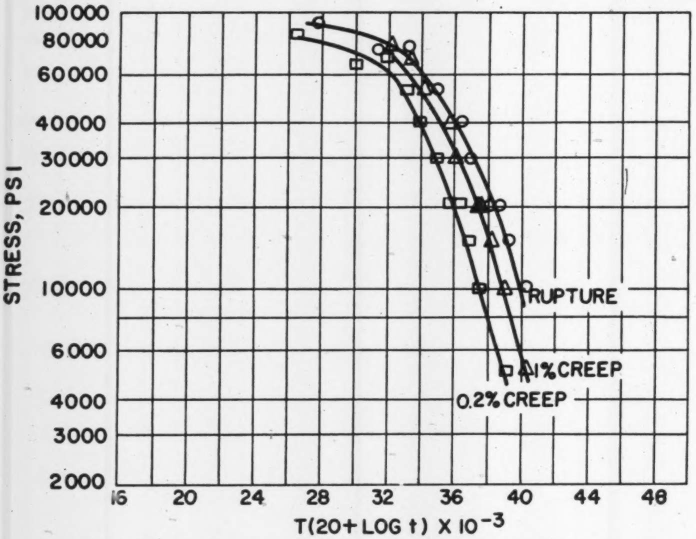

FIG. 15.—Master Rupture Curve for Cold-Rolled 19-9-DL Sheet.

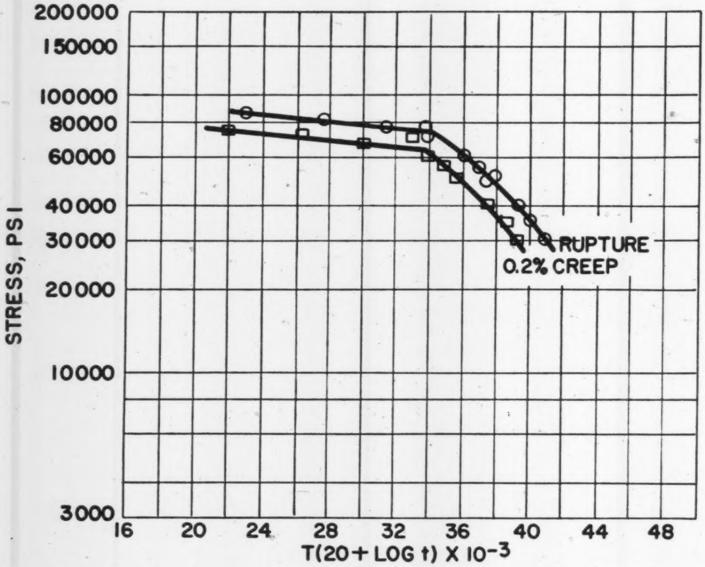

FIG. 16.—Master Rupture Curve for Hot-Cold Rolled H.S. No. 88 Sheet.

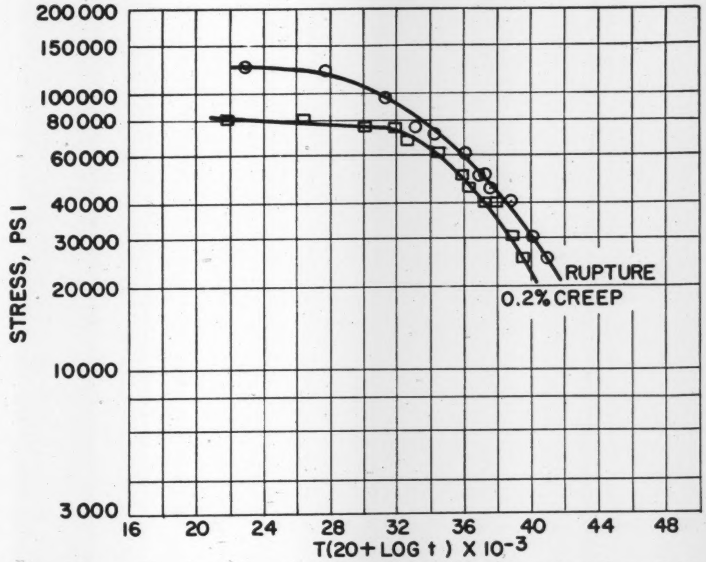

FIG. 17.—Master Rupture Curve for Discalloy 24 Sheet Solution Treated (Aged).

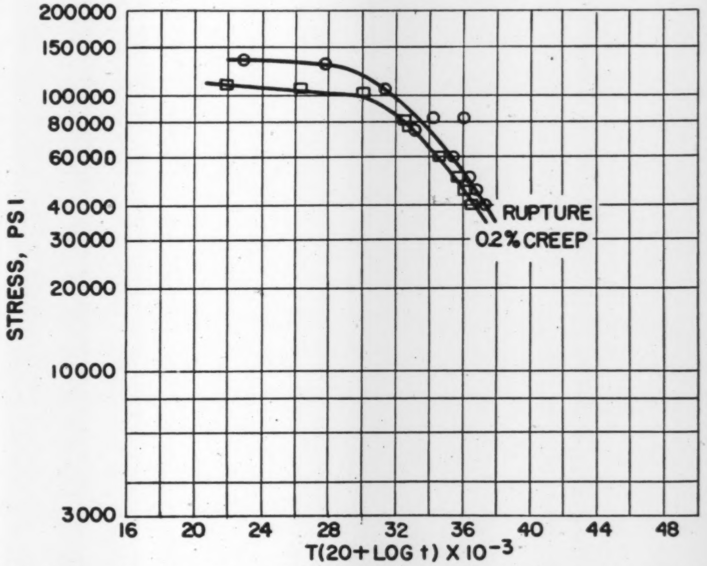

FIG. 18.—Master Rupture Curve for 1650 F Tinidur Sheet Solution Treated (Aged).

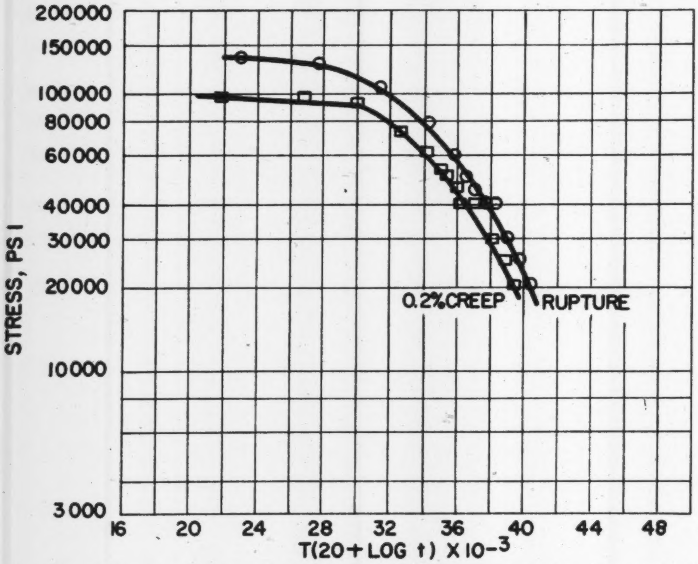

FIG. 19.—Master Rupture Curve for 1875 F Tinidur Sheet Solution Treated (Aged).

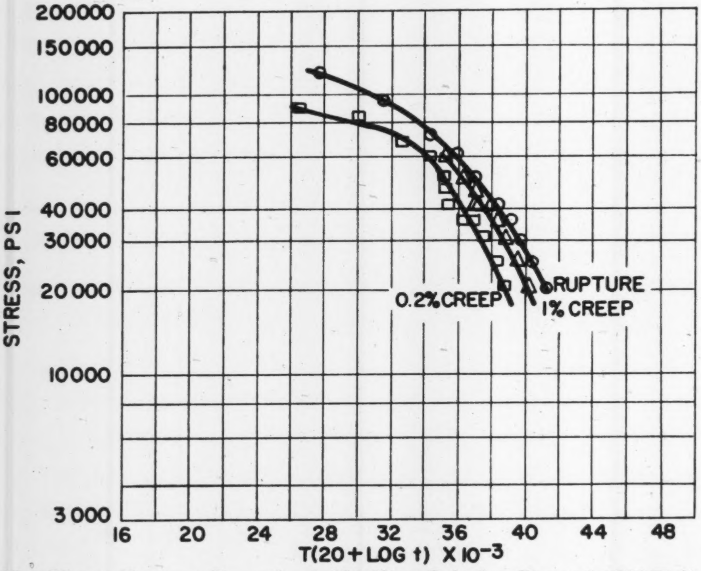

FIG. 20.—Master Rupture Curve for A-286 Sheet Solution Treated 1800 F (Aged).

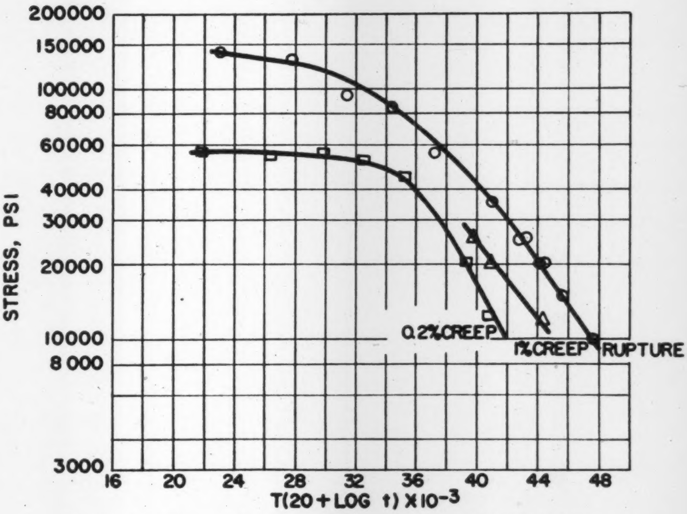

FIG. —21.Master Rupture Curve for Annealed L-605 Sheet.

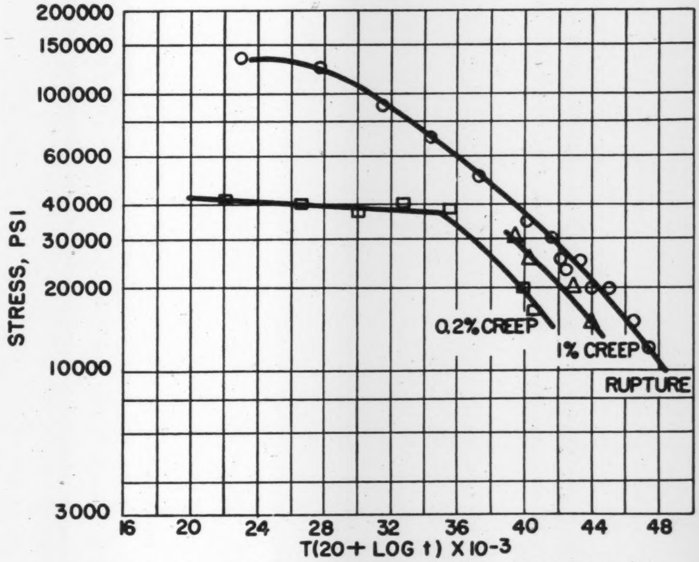

FIG. 22.—Master Rupture Curve for Annealed V-36 Sheet.

form by the Republic Steel Corp. Sheets were hot rolled, annealed at 1950 F for 15 min, air cooled, pickled, and cold reduced to produce a room temperature yield strength (0.002 in. per in. offset) of 104,300 psi. The alloy is composed of two phases—an austenitic matrix and the complex carbide M_6C. Most of the carbide (M_6C) has precipitated as fine particles at the austenitic twin and grain boundaries. A small amount of M_6C may be seen as large spheroidal banded carbide.

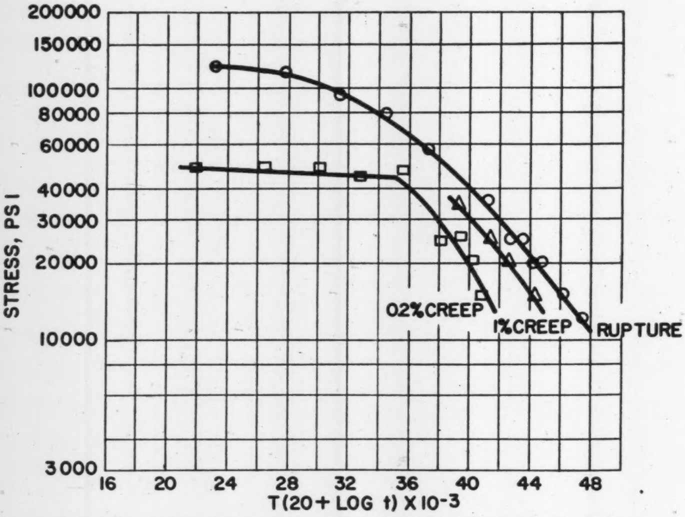

FIG. 23.—Master Rupture Curve for Annealed WF-31 Sheet.

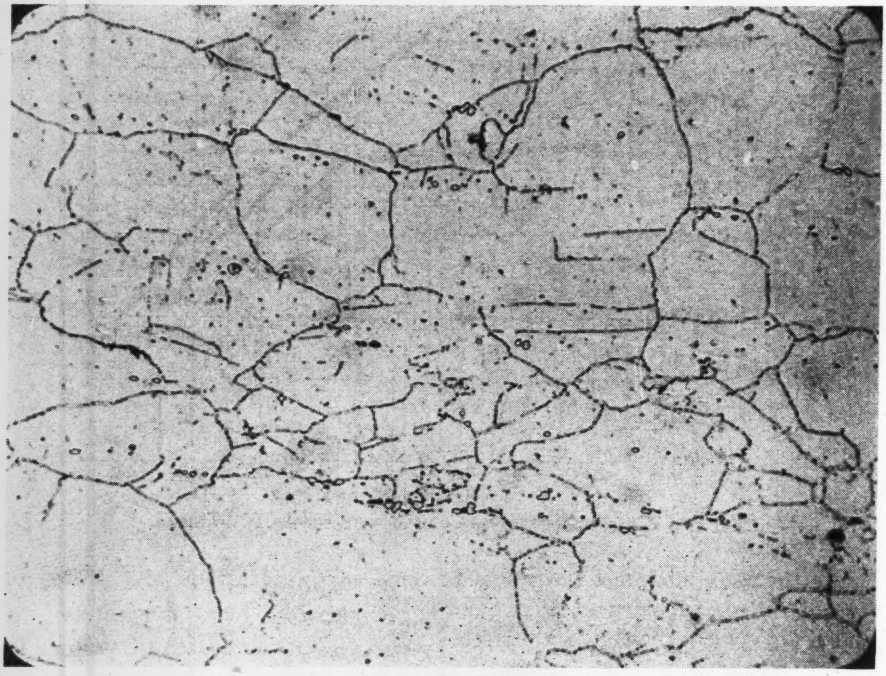

FIG. 24.—Alloy 16-25-6, Hot-Rolled, Annealed 1950 F—Cold Reduced to 104,300 psi, 0.002 in. per in. Yield Strength.

92 per cent HCl—5 per cent H_2SO_4—3 per cent HNO_3 etchant. Immersion etched, 15 sec. (×500).

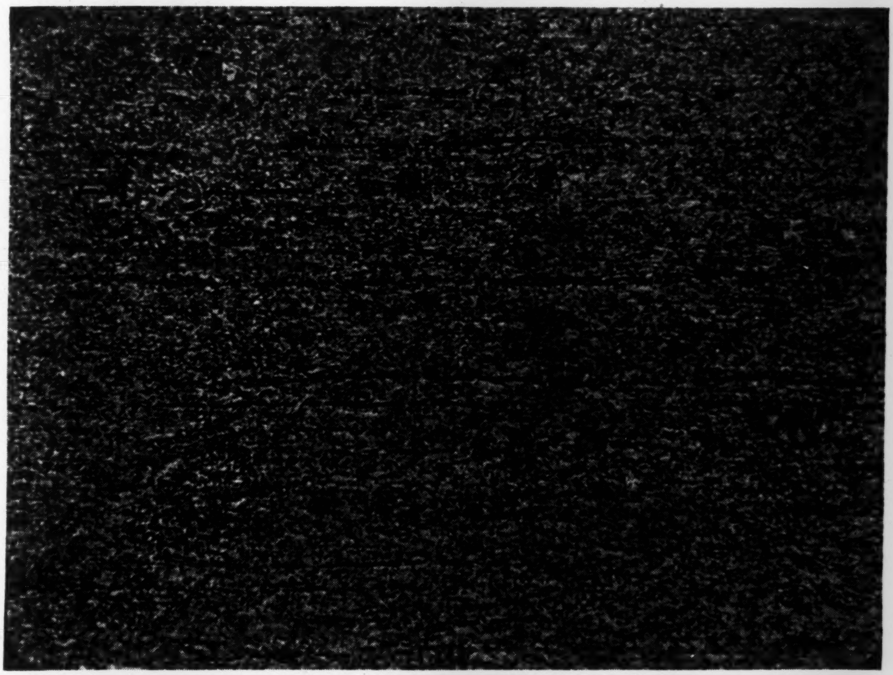

FIG. 25.—Alloy 19-9-DL, Hot-Rolled, Annealed 1800 F.
92 per cent HCl—5 per cent H_2SO_4—3 per cent HNO etchant. Immersion etched, 15 sec. (×500).

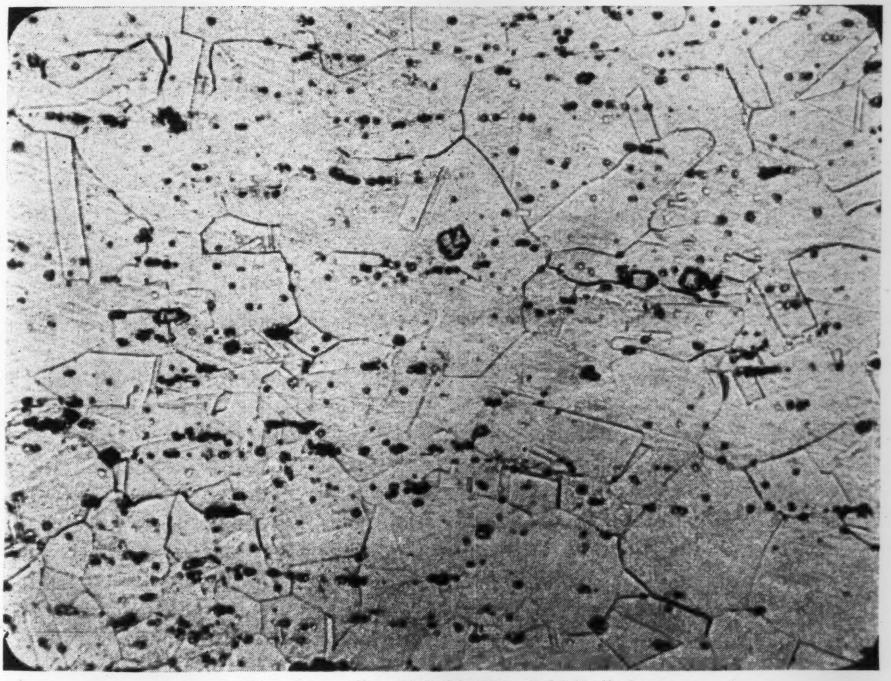

FIG. 26.—Alloy H.S. 88, Hot-Cold Rolled.
92 per cent HCl—5 per cent H_2SO_4—3 per cent HNO_3 etchant. Immersion etched, 15 sec. (×500).

19-9-DL (Fig. 25):

This material was melted and rolled by the Universal Cyclops Steel Corp. Strips were hot rolled, annealed at 1800 F, air cooled, and pickled (0.002 in. per in. offset yield strength of 49,000 psi). In addition, several strips from another heat were cold reduced to produce a yield strength (0.002 in. per in. offset) of 108,350 psi. Rupture specimens of this group were stress relief annealed at 1200 F for 2 hr prior to testing. The microstructure of the alloy in the annealed condition is shown in Fig. 25. The fine directional precipitate is probably $Cr_{23}C_6$, the major constituent in addition to the austenitic matrix. Columbium carbonitride is present in a very small amount, but color differences of the particles indicate that a range of carbon to nitrogen ratios are present. These particles may be seen distributed throughout the extremely small austenite grains as rather large irregular crystals.

H.S. No. 88 (Fig. 26):

These sheets were furnished by the Haynes-Stellite Corp. as hot-cold rolled to a yield strength (0.002 in. per in. offset) of 90,200 psi, and pickled. The alloy is austenitic with very little grain boundary precipitation. Large particles of titanium carbide and some angular crystals of nitrogen rich titanium carbonitrides may be found in the structure. The directional particles, mostly spheroidal, could not be identified from the preliminary X-ray diffraction pattern obtained.

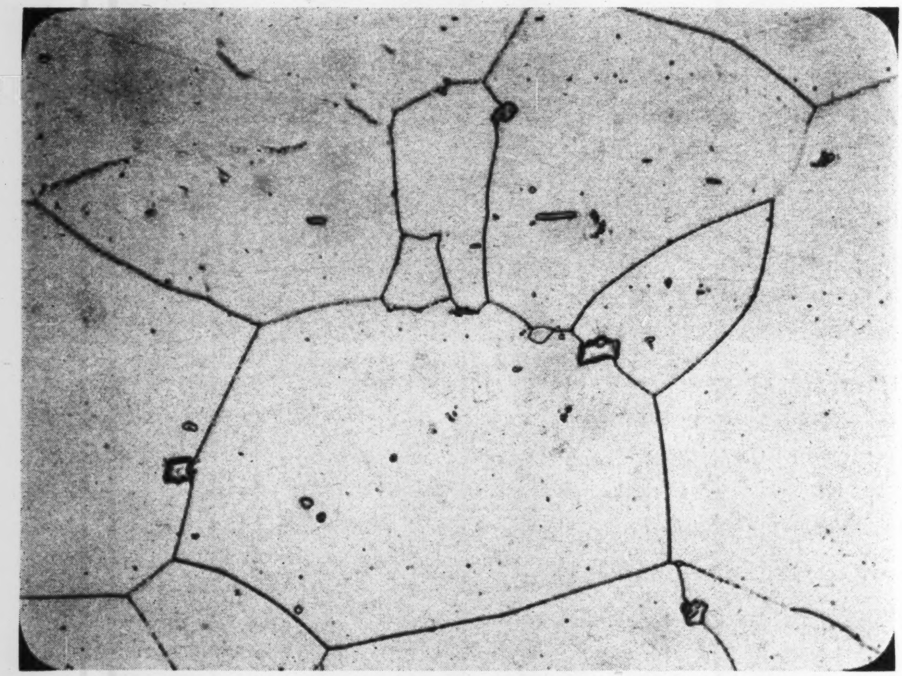

FIG. 27.—Alloy Discalloy 24, Cold-Rolled, Solution Annealed 1950 F, Water Quenched, Aged 1350 F—20 hr, Slow Cooled to 1200 F in 5 hr and Held for 20 hr.

92 per cent HCl—5 per cent H_2SO_4—3 per cent HNO_3 etchant. Immersion etched, 15 sec. (×500).

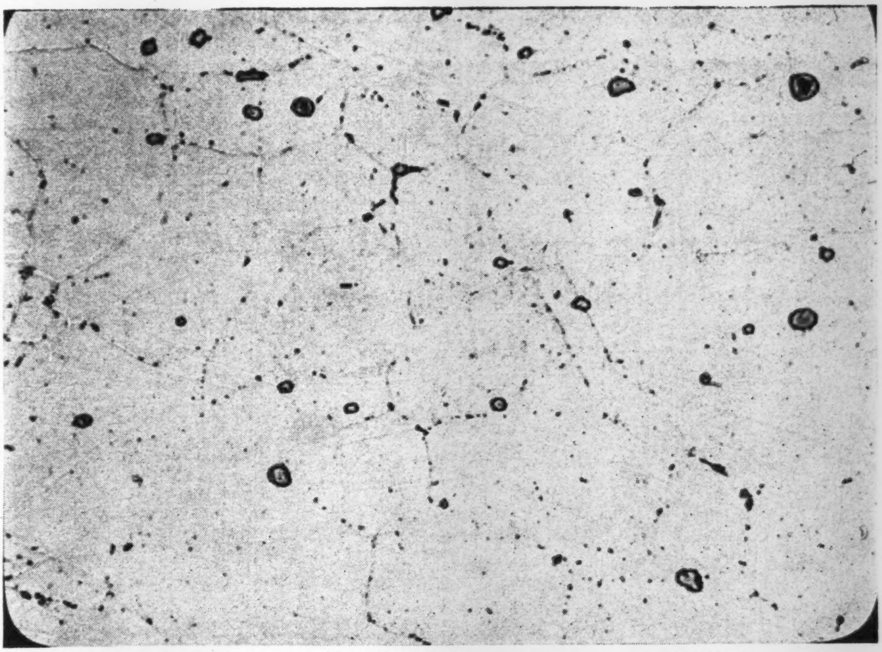

FIG. 28.—Alloy Tinidur, Hot-Rolled Solution Annealed 1650 F, Aged 1200 F—16 hr + 1350 F—16 hr.
10 per cent Oxalic Acid, electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 10 sec. (×500).

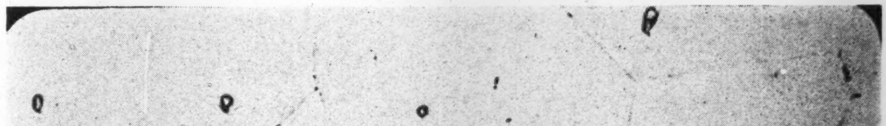

FIG. 29.—Alloy Tinidur, Hot-Rolled, Solution Annealed 1875 F.
Aged 1200 F—16 hr + 1350 F—16 hr 10 per cent Oxalic Acid, electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 10 sec. (×100).

Discalloy 24 (Fig. 27):

This material was furnished by the Westinghouse Electric Co. as cold rolled, solution treated (1950 F 20 min., water quench) and pickled. Prior to testing, samples were aged 20 hr at 1350 F, slow cooled in 5 hr to 1200 F and held at 1200 F for an additional 20 hr. Discalloy 24, A-286, and Tinidur are similar in basic chemical composition and are also somewhat similar in microstructure. All three alloys have one constituent of which the diffraction pattern is identical, but unidentified at the present time. Discalloy 24 also has a small amount of titanium carbide randomly distributed in the matrix as do other alloys with titanium additions. The microstructure shows a nearly continuous grain boundary precipitate.

Tinidur:

This material was supplied by the Allegheny-Ludlum Steel Corp. in two conditions:

1. Hot rolled, solution annealed at 1650 F, air cooled and pickled (Fig. 28).
2. Hot rolled, solution annealed at 1875 F, air cooled and pickled (Fig. 29).

Samples of both lots were aged at 1200 F for 16 hr, air cooled, plus 1350 F for 16 hr, and air cooled prior to testing. The primary difference in microstructure brought about by the two solution treatments is one of grain size and particle size of the precipitates. The structures are otherwise similar. There is a small amount of titanium carbide distributed throughout the matrix and also a grain

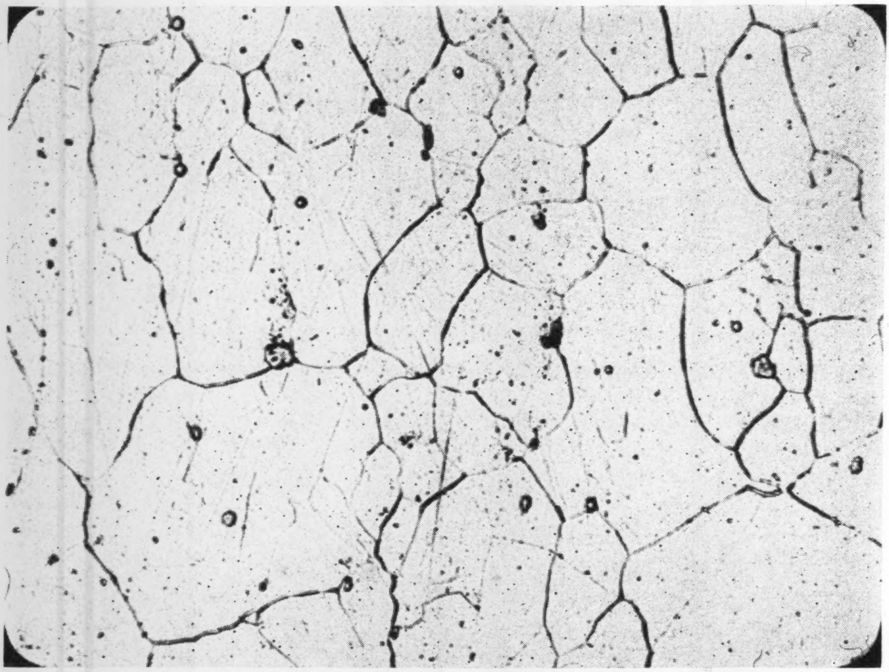

FIG. 30.—Alloy A286, Hot-Rolled, Solution Annealed 1800 F, Aged 1325 F—16 hr.
10 per cent oxalic acid, electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 15 sec. (Over-etched in order to illustrate "ghost grain boundaries") (×500).

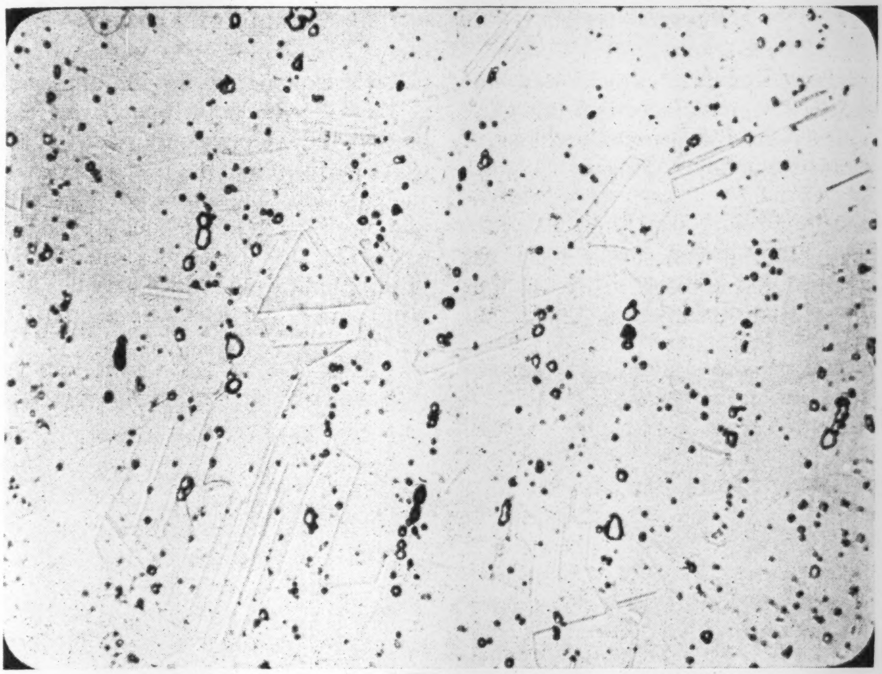

FIG. 31.—Alloy L-605, Hot-Rolled, Solution Annealed 2200 F.

50 ml HCl—100 ml alcohol—2 g $CuCl_2$—2 ml zephrian chloride (modified Kallings etch), electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 5 sec. (×500).

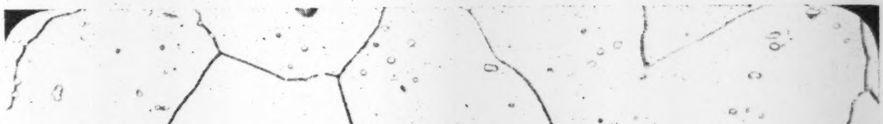

FIG. 32.—Alloy V36, Hot-Rolled, Solution Annealed 2250 F.

100 ml HCl—100 ml Alcohol—5 g $CuCl_2$ (Kallings etch), electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 10 sec. (×500).

boundary precipitate which was not identified. The manufacture of this alloy has since been discontinued and is now superceded by alloy A-286.

A-286 (Fig. 30):

This material was supplied by the Allegheny-Ludlum Steel Corp. as hot rolled, solution annealed at 1800 F, air cooled, and pickled. Tension samples were aged for 16 hr at 1300 F, air cooled, and stress rupture samples aged for 16 hr at 1325 F, air cooled. A normal etching treatment on A-286 results in a fine-particled non-continuous grain boundary precipitation. The sample photographed for Fig. 30 was intentionally overetched in order that a secondary grain pattern might be seen. This has caused a widening of the normal grain boundaries. A possible explanation for the appearance of these "ghost grain boundaries" may be that the temperature or time of solution treatment had not been sufficient for the complete solution of particles which had precipitated at previous grain boundaries. The alloy contains a small amount of titanium carbide which may be seen as large gray particles throughout the structure. The main precipitate phase was not identified.

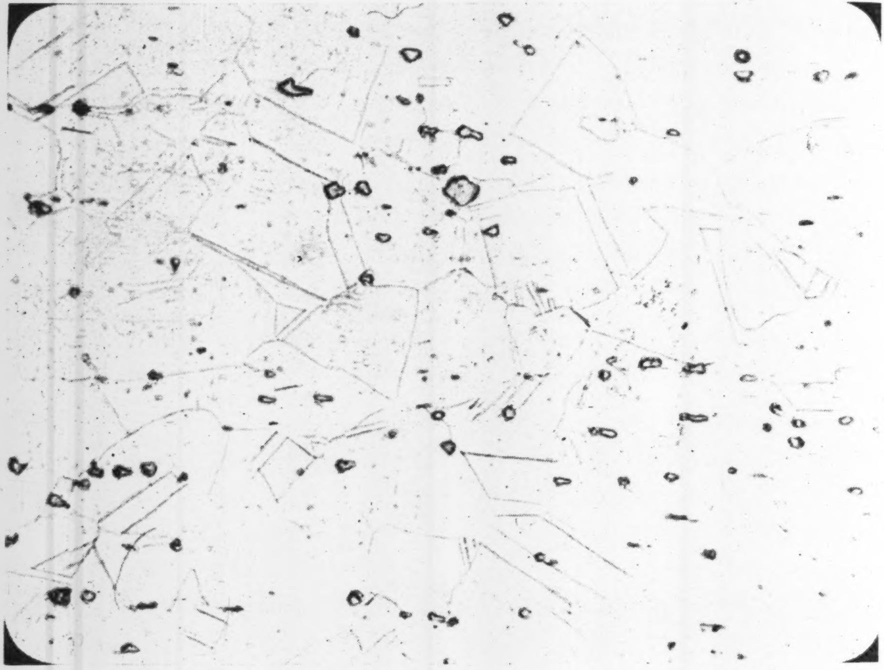

FIG. 33.—Alloy WF31, Hot-Rolled, Solution Annealed 2250 F.
100 ml HCl—100 ml alcohol—5 g $CuCl_2$ (Kallings etch), electrolytic etchant. Specimen the anode, platinum the cathode, 4.5 v, 10 sec. (×500).

L-605 (Fig. 31):

This material was supplied by the Haynes-Stellite Corp. as hot rolled, solution annealed at 2200 F for 10 min., air cooled, and pickled. A selective electrolytic separation technique, similar ot that used on other high temperature alloys was not successful, but the photomicrograph is included for reference.

V-36 (Fig. 32):

This material was supplied by the Allegheny-Ludlum Steel Corp. as hot rolled, solution annealed at 2250 F, air cooled, and pickled. This alloy is a modification of the turbine bucket alloy S-816 and contains the spheroidal, columbium carbide, as well as a grain boundary precipitate which is probably $Cr_{23}C_6$. The matrix is the face-centered-cubic cobalt rich phase.

WF-31 (Fig. 33):

This material was supplied by the Crucible Steel Company of America as hot rolled, solution annealed at 2250 F, air cooled, and pickled. Applied metallographic techniques were also unsuccessful on WF-31 but the photomicrograph is also included for reference.

DISCUSSION OF RESULTS

Short-Time Properties (Tables II, III, IV, V):

On the basis of short-time strength there seems little to justify the use of cobalt base alloys at temperatures of 1500 F or less. In the range from room temperature to the temperature at which the effects of overaging are evident (slightly higher than 1350 F) the precipitation hardened alloys have a strength advantage over the strain hardened alloys. In this range the precipitation hardened alloys are also stronger than the cobalt base alloys in yield strength and are comparable in tensile strength. The strengthening effects of the strain hardening in alloys H.S. No. 88 and Timken 16-25-6 are less drastically reduced by short-time exposures to temperature than are the effects of precipitation hardening, and consequently these alloys are stronger than the precipitation hardening type above the aging temperature. It should be mentioned, however, that once the strain hardened alloys are overheated in service they suffer a permanent loss in strength. This is not true for many age hardening alloys. Scott and Gordon[4] have reported almost complete recovery of hardness and strength on Discalloy 24 by subsequent exposure in the normal aging temperature range and similar results have also been obtained for A-286 on work conducted at the Thompson Lab., General Electric Co. From 1650 F to 1800 F the iron base alloys are effectively annealed and the cobalt base alloys are definitely superior by reason of a stronger matrix.

Elongation values in conjunction with these short-time tests are revealing in that the cold working which has enhanced to various degrees the high temperature properties of the strain hardened alloys has left them with insufficient ductility to allow satisfactory formability. The cold reduction has reduced the elongation at fracture to 20 to 25 per cent, a range not conductive to spinning or drawing without intermediate anneals, a process which would reduce the strength. It is also noticed that the room temperature elongations of alloys Tinidur, Discalloy 24, and A-286 indicate that very little forming is practical after aging. This, of course, would not be the normal sequence of operations. The elongation values for these alloys in the solution annealed conditions are not recorded but vary from 35 to 50 per cent at room temperature and indicate satisfactory formability in this condition.

Strain Hardened Alloys.—Among the strain hardening type alloys, cold rolled 19-9-DL was strongest in yield strength up to 1200 F, although the strength of this alloy decreased so sharply above that temperature that at 1500 F the yield strength (0.002 in. per in. offset) of both the annealed and cold rolled material was only 17,000 psi, less than one-half that of Timken 16-25-6 or H.S. No. 88 (see Table V).

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[4] Howard Scott and R. B. Gordon, "Precipitation, Hardened Alloys for Gas Turbine Service I," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 69, August, 1947, p. 583.

Precipitation Hardened Alloys.—The precipitation hardening type alloys have minor differences in chemical composition, except for molybdenum content. One might expect, therefore, little difference in properties, except possibly in high temperature creep strength and rupture strength. This has been partially borne out in that the tensile strengths of this group are in the same order of magnitude from room temperature to 1800 F, with a sharp decline above the aging temperature. The differences in yield strengths which are observed below 1200 to 1350 F might be attributed to differences in processing and heat treatment. Above the aging temperature the yield strengths are also in the same order of magnitude with the exception of A-286, which appears to have overaged more rapidly than the other age hardening alloys.

Cobalt Base Alloys.—Among the cobalt base alloys, L-605 has a yield strength advantage up to 1500 F, but data at higher temperatures are probably comparable to V-36 and WF-31. The variation of elongation with temperature for each of these alloys can probably be attributed to precipitation hardening during test. All of these alloys contain relatively high percentages of molybdenum or tungsten, or both, which are known to be responsible for aging at temperatures above 1500 F when no load is applied. Under stress the lower limit of the precipitation hardening range is appreciably lowered and could explain the loss of ductility from 1200 to 1500 F. It is also realized that these alloys are extremely work hardenable and that the preparation of the test section will strongly influence elongation values.

Creep and Stress Rupture Properties (Figs. 1 to 23):

When $T(20 + \log t) \times 10^{-3}$ exceeds approximately 36.5 (100 hr at 1200 F), the cobalt base alloys are generally stronger in rupture than the iron base alloys tested, although very little advantage is realized over H.S. No. 88 up to at least 100 hr at 1400 F ($T(20 + \log t) \times 10^{-3} = 41.0$). On the basis of creep strength alone, there is no advantage in using the cobalt base alloys up to $p = 40.0$ (approximately 100 hr at 1350 F) as both H.S. No. 88 and Discalloy 24 are stronger.

Strain Hardened Alloys.—The importance of processing, as well as the chemical composition, as a major factor in the strength of an alloy is suggested by the varied results observed in the strain hardening group (19-DL, H.S. No. 88 and Timken 16-25-6). The excellent strength of cold rolled 19-9-DL is quickly lost with increasing time-temperature combinations as evidenced by the sharp break in the master rupture curve at approximately 100 hr at 1000 F.

The outstanding alloy of this group is H.S. No. 88. The slope of the H.S. No. 88 rupture curve is not as steep as that of Timken, and the master rupture curve illustrates well how H.S. No. 88 has maintained its strength as time-temperature combinations increase. The superiority of H.S. No. 88 is more pronounced in creep. For example, for 100 hr at 1200 F, H.S. No. 88 is 8000 psi stronger than Timken in rupture, but is 21,000 psi stronger in 0.2 per cent creep. The excellent strength of H.S. No. 88 in view of its low alloy content can probably be attributed to the composition (addition of boron) and to the processing (hot-cold reduction), both of which are apt to present other problems. Difficulty has been encountered in the welding of boron steels and considerable experience might be necessary in order to produce consistent results by the hot-cold working processes where cooling rates of various gages would probably be a controlling factor.

Precipitation Hardened Alloys.—As mentioned previously, there is little difference in the composition of the precipitation hardening alloys except in the increasing molybdenum contents, and the variation in rupture strength can undoubtedly be attributed to this difference. The difference in creep strength is more marked, however, and these tests show Discalloy to be definitely superior to the other precipitation hardened alloys in this respect. The superior creep properties of the Tinidurs over A-286 is not explained. Both A-286 and Discalloy 24 exhibit a break in the slope of their rupture curves at 1350 F.

No appreciable difference in strength has been indicated by the two temperatures of solution treatment for Tinidur. A low solution treatment of 1650 F had been used in the hope of increasing rupture ductility, but no improvement in this property was accomplished, and Tinidur appears to be brittle in either condition. Since the beginning of this project, the melting of Tinidur has been discontinued and replaced by A-286, a similar basic analysis with the addition of molybdenum and vanadium.

Cobalt Base Alloys.—Although the rupture strength values of V-36, WF-31, and L-605 are within the same order of magnitude at 1500 F and 1650 F, the creep values of L-605 are slightly lower than corresponding creep values of V-36 and WF-31. The rupture and creep curves of cobalt base alloys have no break in the slope, but a sharp decrease is noticed on the master rupture curve in the region where $T\,(20 + \log t) \times 10^{-3} = 35.5$.

SUMMARY

1. Photomicrographs of nine high-temperature alloys are presented with a general discussion of the microstructure.

2. Creep, stress rupture, and short time tension and yield data from room temperature to 1800 F are presented for these alloys in strip form.

3. Tests were confined to one typical analysis of each alloy and heat to heat variations are not within the scope of this paper.

4. The room temperature properties of strain hardened alloys 19-9-DL H.S. No. 88, and Timken 16-25-6 do not indicate satisfactory formability.

5. The excellent strength of cold rolled 19-9-DL is lost when $T\,(20 + \log t) \times 10^{-3}$ exceeds 32.0 (approximately 100 hr at 1000 F).

6. The high-temperature strength of alloy H.S. No. 88 in creep and stress rupture is exceptionally high in view of its relatively low alloy content.

7. At 1200 F and 1350 F the creep strength of Discalloy 24 is appreciably higher than the other precipitation hardened alloys studied.

8. On the basis of short time strength, there is no advantage in using the cobalt base alloys investigated at temperatures of 1500 F or less.

9. When $T\,(20 + \log t) \times 10^{-3}$ exceeds approximately 36.5 (100 hr at 1200 F) the cobalt base alloys are generally stronger in rupture than the iron-base alloys, although very little advantage is realized over H.S. No. 88 up to $T\,(20 + \log t) \times 10^{-3} = 41.0$.

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chairmanship of Mr. L. Schapiro, Douglas Aircraft Corp., Santa Monica, California. The program was outlined by a subcommittee consisting of W. L. Badger, Chairman Project AP-2 General Electric Co., P. G. DeHuff, Westinghouse Electric Co., A. W. F. Green, General Motors Corp., and R. H. Thielemann, Pratt & Whitney Aircraft Co.

Short-time tension and yield tests were conducted by the Pratt and Whitney Co. Microscopy, creep and stress-rupture tests were conducted by the Thomson Lab., General Electric Co. Thermal shock and fatigue properties are presently being determined by the General Motors Corp. and the Westinghouse Electric Co., respectively, but data was not available for this presentation.

All materials were donated by the respective vendors.

DISCUSSION

Mr. J. W. Freeman.[1]—Mr. Preston shows curves for alloys which I presume are from one particular lot of sheet with somewhat unknown prior history. I think the curves reported, particularly for rupture strength, would be quite consistent for the particular lots of samples. It is my impression from having done considerable work on the processing variables that are involved in producing sheets, particularly those which were classified as the strain-hardening type, that they could be radically changed in their position on the rupture curves by suitable modifications of prior history. For this reason I ask for comment on the degree to which the reported properties for the various alloys might vary from lot to lot and particularly from different producers. In particular, it would be helpful to those who may attempt to use the data to know whether this might be greater than some of the differences between alloys shown by the data.

Mr. D. Preston (*author*).—It is certainly recognized that the high-temperature properties of austenitic sheet materials will vary from heat to heat. Only a limited amount of material was available for this investigation, however, and to what degree these properties would vary was not within the scope of this paper. In order to minimize this influence, the vendors were asked to supply their respective alloys with typical compositions and processing. This information is included in the paper.

One might surmise that the mechanical properties of an age hardening alloy would be generally more consistent from heat to heat than the properties of a strain-hardened alloy, but I would hesitate to comment more specifically without additional data.

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ATMOSPHERIC CORROSION OF STEEL WIRES*

By A. P. Jahn[1]

ASTM Committee A-5 on Corrosion of Iron and Steel has been conducting a test of steel wire and wire products exposed for atmospheric corrosion for the past 15 years. This is probably the most extensive test of its kind which has ever been conducted and most of the leading steel wire manufacturers are represented on its committee. Although 15 years have already elapsed and the data from wires exposed at some sites are almost completed, other sites have as yet shown only that atmospheric corrosion is an extremely slow process in many parts of the country. Completion of the tests at these latter sites seems to be 20 or more years away.

The sites at which the wires are exposed represent such diverse types as industrial, seacoast, and rural. Seven of the sites are rural and are so widely scattered that they represent the rural atmospheric conditions prevailing throughout the whole country. The location of the test sites, their general classification regarding atmospheres, and the present state of corrosion of galvanized wires exposed there are as follows:

Test Location	Type of Atmosphere	Remarks	Corrosion State After 15 yr
Pittsburgh, Pa.	Severe Industrial	On Brunot Island	All galvanized items 100 per cent rusted
Bridgeport, Conn.	Industrial	In the city	Coating up to 1¾ oz per sq ft rusted
Sandy Hook, N. J.	Seacoast	About 300 yd from Atlantic Ocean	Coatings up to 1¾ oz per sq ft rusted
State College, Pa.	Rural	Central Pennsylvania	Coating up to 1 oz per sq ft rusted
Lafayette, Ind.	Rural	Wabash River Valley	Coatings up to 1 oz per sq ft rusted
Ithaca, N. Y.	Rural	Central N. Y.	Coatings up to 1 oz per sq ft rusted
Ames, Iowa	Rural	Central Iowa	Coating up to ¾ oz per sq ft rusted

College Station, Tex.; Manhattan, Kan.; Davis, Calif. are additional rural sites and Santa Cruz, Calif. (about 3 miles from Pacific Ocean) is another seacoast type of exposure. Corrosion has progressed very slowly at these four sites. Fifteen years of exposure has produced some rusting on wires with coatings up to ½ oz per sq ft, but the rusting so far has been insufficient to warrant inclusions of data from these sites in the summaries that follow.

PURPOSE

In ASTM *Proceedings*, Committee A-5 has published detailed reports concerning the specimens exposed and the progress of the tests. This paper is based on these reports, which contain descriptions of the test methods, chemical analyses, micrographs and other characterizations of specimens in the test as well as the data assembled during inspections, published in the ASTM *Proceedings* for 1937, 1939, 1941, 1943, 1945, 1947, 1949, and 1951. This summary is an attempt to bridge the gap between the general finding that "everything corrodes everywhere" and the mass of detailed data accumulated in the tests, keeping to a minimum the tabular data necessary to show test results adequately and to support conclusions. Illustrative figures are included in order to show the trend and scope of the tabular data.

The specimens on exposure are unfabricated wires, fences, barbed wire, and strand. The wires, fences, and strand of corrosion-resistant steel, lead-coated or copper-coated mild steel included in the test have deteriorated only superficially. This summary and discussion are devoted almost entirely to the bare steel and galvanized steel specimens. The unfabricated wires are nearly all galvanized steel, although some corrosion-resistant steel wire, lead-coated wires, copper-coated wires, and uncoated wires are included. There are about 100 different wires lots at each of eleven locations, each wire lot having seven identical specimens at each location. The 85 galvanized mild steel wire lots represent the major portion of the test. These wires are of five different gages, carry zinc coatings ranging from 0.25 to 3.00 oz per sq ft, and represent the leading commercial methods of galvanizing. These tests can be expected to provide answers to questions of interest to both producers and consumers, such as:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Member of the Technical Staff, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

1. In various locations what is the relation between weight of zinc coating and service life before rusting?
2. Is the effectiveness of the same weight of zinc coating materially altered by the particular method of its application?
3. Is life of zinc coating a function of wire diameter?
4. What is the service life, from a strength standpoint, of wire after the zinc coating has failed?
5. Is this service life materially different for so-called copper-bearing steel or rephosphorized steel than for other steel?

ZINC-COATED SPECIMENS

Coating Processes:

To answer some of these questions it was necessary to characterize the specimens according to weight of coating and method of galvanizing. The coating

TABLE I.—LOSS OF ZINC—OZ PER SQ FT PER YR AND CORROSION RATES.

Wire	Coat	Iron, per cent	Type	Pittsburgh, Pa.			Sandy Hook, N. J.			State College, Pa.		
				Weight Loss	$Z_{1}R$	$Z_{100}R$	Weight Loss	$Z_{1}R$	$Z_{100}R$	Weight Loss	$Z_{1}R$	$Z_{100}R$
1	*2*	*3*	*4*	*5*	*6*	*7*	*5*	*6*	*7*	*5*	*6*	*7*
No. 148	0.90	6.8	CH	0.337	0.333	0.250	0.107	0.130	0.095	0.061	0.068	[a]
No. 346	0.88	5.2	CH	0.385	0.345	0.293	0.116	0.135	0.117	0.061	0.070	[a]
No. 542	0.70	6.4	CH	0.448	0.437	0.350	0.122	0.127	0.113	0.066	0.067	0.056
Average	0.83	6.1	CH	0.390	0.370	0.297	0.115	0.131	0.108	0.063	0.068	0.056
No. 247	0.96	6.2	HT	0.347	0.331	0.246	0.123	0.141	0.113	0.068	0.078	[a]
No. 345	0.84	6.9	HT	0.357	0.323	0.263	0.131	0.143	0.112	0.068	0.078	0.062
No. 541	0.76	6.6	HT	0.365	0.292	0.217	0.139	0.139	0.117	0.060	0.072	0.061
Average	0.85	6.6	HT	0.356	0.315	0.262	0.131	0.141	0.114	0.065	0.076	0.061
No. 248	0.81	0.09	EG	0.332	0.386	0.335	0.098	0.101	0.095	0.050	0.061	[a]
No. 348	1.05	0.04	EG	0.349	0.328	0.269	0.102	0.109	0.095	0.053	[a]	[a]
No. 540	0.70	0.12	EG	0.402	0.378	0.293	0.112	0.119	0.093	0.055	0.054	[a]
Average	0.85	0.08	EG	0.361	0.364	0.299	0.104	0.110	0.094	0.053	0.057	[a]
Over-all Average				0.369	0.336	0.286	0.117	0.127	0.105	0.060	0.068	0.060

Col. 1. Identifying number of the wire lot: When the first digit is: 5 4 3 2 1
The respective gages are: 14½ 12½ 11 9 6

The second and third digit indicate the group of zinc coating weights for example: 45 to 49 = 0.80 to 1.00 oz per sq ft group.

Col. 2 Zinc coating weight oz per sq ft, of all stripping determinations.

Col. 3 Per cent iron in the coating.

Col. 4 Code for type of galvanizing: CH = Charcoal-Wiped Hot-Dip
HT = Hot-Dipped Heat-Treated
EG = Electro-galvanized

Col. 5 Loss of zinc oz per sq ft per yr as determined by weight loss tests.

Col. 6 Corrosion Rate. Coating Weight divided by years to first rust.

Col. 7 Corrosion Rate. Coating Weight divided by years to 100 per cent rust.

[a] Specimen not yet sufficiently rusted for determination.

TABLE II.- OBSERVED YEARS UNTIL RUST AND CALCULATE

					Pittsburgh, Pa.				Sandy Hook, N.J.				Bridgeport, Conn.			
Coating Group	1 Wire No.	2 Coat	3 % Fe	4 Type	5 1R	6 100R	7 Z_{1R}	8 Z_{100R}	5 1R	6 100R	7 Z_{1B}	8 Z_{100R}	5 1B	6 100R	7 Z_{1R}	8 Z_{100}
0.20 to 0.30 Avg. 0.28	512	0.27	6.4	TH	0.5	1.0	.540	.270	1.5	2.5	.180	.108	1.6	2.6	.169	.104
	410	0.30	6.5	TH	0.6	1.1	.500	.273	1.8	2.9	.167	.103	1.8	2.8	.167	.107
	411	0.28	6.9	TH	0.8	1.4	.350	.200	1.8	2.9	.155	.097	2.3	2.9	.122	.097
	510	0.29	8.7	TH	1.2	1.7	.242	.170	1.7	2.9	.170	.100	2.5	2.9	.116	.100
	412	0.29	8.7	TH	1.2	1.7	.242	.170	2.5	2.9	.116	.100	2.5	2.9	.116	.100
	511	0.24	9.2	TH	0.6	1.0	.400	.240	1.7	2.8	.141	.086	1.8	2.8	.133	.086
0.25 to 0.35 Avg. 0.30	315	0.25	5.7	TH	0.4	0.8	.625	.313	1.6	2.6	.156	.096	1.7	2.8	.147	.089
	215	0.28	6.3	TH	0.6	1.0	.467	.280	1.8	3.0	.155	.094	1.8	3.0	.155	.094
	117	0.27	6.0	TH	0.7	1.5	.385	.180	2.7	3.0	.100	.090	2.7	3.8	.100	.071
	317	0.38	7.9	TH	1.4	1.9	.272	.200	3.7	4.5	.104	.085	2.8	4.5	.136	.085
	217	0.36	7.1	TH	1.1	1.5	.327	.240	2.8	3.8	.129	.095	2.7	3.8	.133	.095
	316	0.32	7.9	TH	1.2	1.6	.267	.200	2.7	3.0	.118	.106	2.5	3.5	.128	.092
	216	0.30	8.1	TH	1.3	1.7	.231	.177	2.5	3.0	.120	.100	2.8	3.6	.107	.084
	115	0.25	8.3	TH	0.6	1.5	.416	.167	1.7	3.0	.147	.083	1.7	2.8	.147	.089
0.35 to 0.45 Avg. 0.38	520	0.36	7.3	TH	1.2	1.6	.300	.225	2.7	3.0	.133	.120	2.5	2.9	.144	.124
	422	0.35	6.9	TH	1.5	1.9	.234	.184	2.9	3.9	.121	.090	2.7	3.8	.129	.092
	423	0.31	7.1	TH	1.2	1.7	.258	.182	2.7	3.7	.115	.084	2.5	3.7	.124	.084
	522	0.44	7.5	TH	1.5	1.9	.293	.232	2.9	3.7	.152	.119	3.4	3.9	.129	.113
	282	0.37	7.2	TH	1.5	1.9	.247	.195	2.8	3.7	.132	.100	2.8	3.9	.132	.100
	521	0.38	9.1	HT	1.7	2.6	.224	.146	2.9	3.9	.131	.098	3.4	3.9	.112	.098
	421	0.47	8.1	HT	1.6	2.5	.294	.188	2.8	3.9	.168	.120	2.7	3.8	.174	.124
0.45 to 0.55 Avg. 0.47	325	0.44	4.1	TH	1.7	2.8	.259	.157	3.8	4.9	.116	.090	3.9	5.5	.113	.080
	228	0.50	6.8	TH	1.6	1.9	.313	.263	2.9	4.8	.173	.104	3.8	5.5	.132	.091
	329	0.54	6.8	HT	1.8	2.9	.300	.186	3.8	5.6	.142	.097	3.8	5.8	.142	.094
	227	0.52	7.9	HT	2.5	2.7	.208	.192	4.4	5.7	.118	.091	4.4	5.8	.118	.091
	125	0.41	6.5	HT	1.5	1.9	.274	.216	3.5	4.0	.117	.103	3.7	4.5	.111	.091
	127	0.54	7.6	TH	1.7	2.5	.318	.216	3.9	5.0	.138	.108	4.0	5.0	.135	.108
	326	0.38	8.5	TH	1.4	1.9	.272	.200	3.8	5.6	.100	.068	2.9	5.8	.131	.066
	226	0.45	7.6	TH	1.9	2.7	.236	.167	3.9	6.5	.115	.069	3.9	6.5	.115	.069
	327	0.47	8.1	TH	1.8	2.9	.261	.162	3.8	4.9	.124	.096	3.9	5.7	.120	.083
	225	0.45	8.5	TH	1.9	2.7	.237	.167	3.9	5.0	.115	.090	3.9	5.8	.115	.078
0.50 to 0.60 Avg. 0.56	530	0.61	.07	EG	1.4	1.7	.436	.359	4.5	6.6	.135	.093	5.4	6.0	.113	.102
	432	0.57	.14	EG	1.6	2.0	.357	.285	6.5	7.0	.088	.082	5.4	6.5	.106	.088
	531	0.60	4.8	CH	1.4	1.8	.428	.333	4.7	5.7	.128	.105	4.7	5.7	.128	.105
	431	0.48	7.8	TH	1.6	2.0	.300	.240	3.5	4.9	.137	.098	3.5	4.5	.137	.107
	430	0.54	8.7	HT	2.6	3.0	.208	.180	4.4	5.7	.123	.095	4.8	6.0	.112	.090
0.60 to 0.70 Avg. 0.65	338	0.69	.04	EG	2.0	2.4	.345	.287	7.9	8.6	.087	.080	6.7	7.8	.103	.088
	236	0.68	.12	EG	2.0	2.4	.340	.283	7.7	8.4	.088	.081	6.8	7.7	.100	.088
	335	0.61	5.9	CH	1.6	2.0	.381	.305	4.9	5.9	.125	.103	5.4	5.9	.113	.103
	237	0.63	5.0	CH	1.8	2.5	.350	.252	4.4	8.0	.143	.079	4.9	8.5	.129	.074
	135	0.74	5.5	CH	2.6	2.9	.285	.255	5.9	7.0	.125	.106	4.9	8.0	.151	.093
	337	0.57	6.2	HT	2.5	3.0	.228	.190	4.8	5.9	.119	.097	5.4	6.0	.106	.095
	235	0.67	6.5	HT	2.6	3.1	.258	.216	5.5	7.0	.122	.096	5.7	7.5	.117	.089
	239	0.65	6.7	CH	2.6	2.9	.250	.224	5.5	6.5	.118	.100	4.4	6.7	.148	.097
	138	0.67	6.4	CH	2.0	2.9	.335	.231	5.5	5.9	.122	.114	4.9	6.6	.137	.102
	139	0.64	7.2	HT	1.9	2.9	.337	.220	4.8	6.6	.133	.097	4.9	7.0	.131	.092
	336	0.66	7.4	HT	2.7	3.7	.244	.178	4.8	5.9	.138	.112	5.4	6.5	.122	.102
	238	0.60	7.7	HT	1.9	2.9	.315	.207	4.8	5.9	.125	.102	4.9	6.5	.122	.092
0.70 to 0.85 Avg. 0.75	540	0.70	.12	EG	1.8	2.4	.390	.292	6.4	7.5	.110	.093	6.2	7.0	.113	.100
	442	0.72	.10	EG	2.0	2.4	.360	.300	7.4	8.0	.097	.090	6.3	7.0	.114	.103
	543	0.79	3.3	CH	1.8	2.7	.439	.292	5.9	8.0	.134	.099	5.9	8.5	.134	.093
	441	0.78	3.8	CH	1.9	2.7	.410	.289	6.5	7.5	.120	.104	5.9	7.5	.132	.104
	542	0.70	6.4	CH	1.6	2.0	.437	.350	5.5	6.2	.127	.113	5.5	6.0	.127	.117
	443	0.74	5.5	CH	1.9	2.7	.390	.274	5.9	7.5	.125	.099	5.8	7.5	.127	.099
	495	0.74	5.5	CH	1.9	2.7	.390	.274	5.9	7.6	.125	.097	5.9	7.6	.125	.097
	541	0.76	6.6	HT	2.6	3.5	.292	.217	5.4	6.5	.139	.117	4.9	6.5	.155	.117
	440	0.76	6.7	HT	2.6	2.9	.292	.262	4.7	5.9	.162	.129	4.8	5.9	.158	.129
	444	0.87	6.4	HT	2.7	3.5	.322	.248	5.7	6.9	.152	.126	5.6	7.5	.155	.116
0.80 to 1.00 Avg. 0.88	348	1.05	.04	EG	3.2	3.9	.328	.269	10.4	11.0	.101	.095	9.3	10.7	.113	.098
	248	0.81	.09	EG	2.1	2.4	.386	.335	7.4	8.5	.109	.095	6.8	7.8	.119	.104
	347	0.88	3.8	CH	2.6	3.0	.339	.293	7.8	9.0	.113	.098	6.9	9.0	.129	.098
	246	0.95	3.7	CH	2.9	3.9	.328	.244	7.9	10.0	.120	.095	6.9	10.0	.138	.095
	346	0.88	5.2	CH	2.5	3.0	.345	.293	6.5	7.5	.135	.117	6.9	8.5	.128	.104
	245	0.81	5.4	CH	2.4	2.9	.337	.280	5.9	7.0	.137	.116	5.9	7.5	.137	.108
	296	0.81	5.4	CH	2.5	3.0	.324	.270	6.4	8.0	.127	.101	6.9	9.0	.118	.090
	148	0.90	6.8	CH	2.7	3.6	.333	.250	6.9	9.5	.130	.095	6.9	9.0	.130	.100
	149	0.85	6.4	CH	2.7	3.5	.315	.243	6.8	9.5	.125	.089	6.9	9.5	.123	.089
	345	0.84	6.9	HT	2.6	3.2	.323	.263	5.9	7.5	.143	.112	5.7	7.8	.147	.108
	247	0.96	6.2	HT	2.9	3.9	.331	.246	6.5	8.5	.141	.113	5.9	9.5	.168	.123
Avg. 1.28	800	1.35	4.6	CH	3.9	6.0	.347	.225	9.9	12.0	.137	.112	9.5	12.5	.142	.108
	801	1.20	4.7	CH	3.5	4.0	.343	.300	8.9	11.0	.135	.109	8.5	10.5	.141	.114
1.60 to 1.80 Avg. 1.76	552	2.08	.04	EG	4.9	5.5	.425	.378	-	-	-	-	14.0	-	.149	-
	451	1.83	.04	EG	4.5	4.9	.407	.373	-	-	-	-	13.0	14.5	.141	.126
	350	1.75	.02	EG	5.0	5.6	.350	.313	-	-	-	-	-	-	-	-
	252	1.69	.07	EG	4.5	5.3	.375	.319	-	-	-	-	13.0	-	.130	-
	351	1.65	.60	SP	3.9	5.6	.424	.295	11.9	-	.139	-	10.4	-	.158	-
	25[illegible]	1.76	.55	SP	3.9	6.0	.453	.294	12.0	-	.147	-	10.4	-	.168	-
	551	1.69	.09	EG	4.5	5.9	.375	.287	-	-	-	-	13.0	-	.130	-
	450	1.50	1.4	SP	3.5	5.0	.430	.300	11.9	-	.126	-	10.0	13.5	.150	.111
	352	1.75	1.4	SP	4.0	6.0	.438	.292	11.9	-	.147	-	10.7	-	.164	-
	251	1.86	1.6	SP	3.9	6.0	.476	.310	9.5	-	.197	-	9.9	-	.187	-
	151	1.86	1.3	SP	3.3	6.0	.564	.310	9.0	-	.207	-	10.4	-	.179	-
Heavy Avg. 2.89	397	2.80	.02	EG	7.4	7.9	.378	.356								
	298	2.72	.01	EG	7.6	8.3	.359	.329								
	299	3.03	1.3	SP	6.9	9.0	.440	.336								

PLATE I
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 52
JAHN ON CORROSION OF STEEL WIRES

LATED CORROSION RATES AT VARIOUS SITES.

	State College, Pa.				Lafayett , Ind.				Ithaca, N. Y.				Ames, Iowa			
8	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8
Z_{100R}	1R	100R	Z_{1R}	Z_{100R}	1R	100R	Z_{1R}	Z_{100R}	1R	100R	Z_{1R}	Z_{100R}	1R	100R	Z_{1R}	Z_{100R}
.104	4.5	5.7	.060	.047	3.9	5.3	.069	.051	5.4	6.1	.050	.044	5.5	6.0	.099	.045
.107	4.5	5.5	.067	.055	4.0	5.0	.075	.060	5.5	6.0	.055	.050	5.5	6.0	.055	.050
.097	5.5	6.7	.051	.041	5.0	5.9	.056	.047	5.6	6.3	.050	.043	6.7	8.1	.042	.035
.100	5.7	6.8	.051	.043	5.2	5.9	.056	.049	5.6	6.3	.052	.046	7.4	8.2	.039	.035
.100	5.7	6.8	.051	.043	5.0	5.9	.058	.049	5.9	6.5	.059	.045	6.7	8.6	.043	.034
.086	4.7	5.9	.051	.041	4.6	5.8	.052	.041	5.4	6.1	.044	.039	6.2	8.2	.039	.029
.089	3.6	5.5	.070	.045	3.8	5.1	.066	.049	4.8	6.0	.052	.042	5.3	6.0	.047	.042
.094	3.6	5.5	.078	.051	4.0	5.8	.070	.048	4.9	7.0	.057	.040	5.5	8.0	.051	.035
.071	4.7	6.5	.057	.042	4.6	5.9	.059	.046	5.2	7.0	.052	.039	6.5	8.5	.042	.032
.085	6.8	8.8	.056	.043	6.4	8.2	.059	.046	6.9	9.2	.055	.041	9.6	13.0	.040	.029
.095	5.5	7.4	.065	.049	5.0	6.6	.072	.055	6.2	8.0	.058	.045	7.7	9.9	.047	.036
.092	5.7	6.9	.056	.046	5.1	6.2	.063	.052	6.1	7.2	.052	.044	7.7	9.9	.042	.032
.084	5.7	7.4	.053	.041	5.2	6.7	.058	.045	6.2	7.4	.048	.041	7.7	10.0	.039	.030
.089	3.7	5.9	.067	.042	4.2	5.7	.059	.044	4.6	6.3	.054	.040	5.3	9.0	.047	.028
.124	6.3	7.7	.056	.047	5.2	6.2	.069	.058	6.2	7.0	.058	.051	7.3	9.5	.049	.038
.092	6.8	8.5	.051	.041	5.9	7.1	.059	.049	6.9	8.2	.051	.043	8.8	12.2	.040	.029
.084	5.8	7.7	.053	.040	5.3	6.3	.058	.049	6.4	7.8	.048	.040	7.7	9.9	.040	.032
.113	7.5	8.3	.058	.053	6.2	7.2	.071	.061	6.9	8.7	.064	.051	9.6	12.0	.046	.037
.100	6.7	8.6	.055	.043	5.0	7.5	.074	.049	6.8	8.6	.054	.043	8.9	12.0	.042	.031
.098	6.8	8.7	.056	.044	5.5	6.7	.069	.057	6.9	8.7	.055	.044	8.9	12.0	.043	.032
.124	6.3	8.4	.075	.056	5.3	6.6	.089	.071	6.8	8.3	.069	.057	7.9	12.0	.059	.039
.080	7.8	9.9	.056	.044	7.0	8.6	.063	.051	7.9	10.0	.056	.044	11.0	14.5	.040	.030
.091	7.8	9.0	.064	.055	6.0	9.0	.083	.055	7.9	9.4	.063	.053	9.9	14.0	.050	.036
.094	7.3	10.8	.073	.050	6.0	9.5	.090	.057	7.9	10.7	.063	.050	9.9	—	.054	—
.091	8.7	11.4	.060	.043	7.9	9.5	.066	.055	9.8	10.9	.053	.048	11.0	—	.047	—
.091	7.3	8.7	.056	.047	6.0	8.1	.068	.051	6.9	9.0	.060	.046	8.8	12.0	.047	.034
.108	8.7	10.3	.062	.048	7.8	9.2	.069	.059	8.9	10.9	.061	.050	11.0	—	.049	—
.066	6.5	10.2	.059	.037	6.5	9.1	.059	.042	6.9	10.0	.055	.038	9.9	15.0	.038	.025
.069	8.7	11.3	.052	.040	7.9	10.0	.057	.045	8.9	12.0	.051	.037	11.0	—	.041	—
.083	8.0	10.5	.059	.045	7.6	9.2	.062	.051	9.0	10.3	.052	.046	11.9	15.0	.040	.031
.078	8.0	10.6	.056	.042	7.9	10.0	.057	.045	9.0	10.9	.050	.041	12.9	—	.035	—
.102	11.3	13.6	.054	.045	9.9	11.0	.062	.055	10.7	12.1	.057	.050	12.8	14.0	.048	.044
.088	11.0	13.5	.052	.042	10.0	11.4	.057	.050	10.8	12.2	.053	.047	12.9	—	.044	—
.105	9.0	11.3	.066	.053	7.8	9.2	.077	.065	9.0	10.8	.067	.056	11.8	13.0	.051	.046
.107	7.7	8.8	.062	.055	6.7	8.2	.072	.058	7.9	9.3	.061	.052	11.8	13.8	.041	.035
.090	8.7	11.3	.062	.048	8.3	10.0	.065	.054	9.0	11.5	.060	.047	11.0	—	.049	—
.088	12.0	15.0	.058	.046	10.8	13.2	.064	.052	12.0	13.8	.058	.050	—	—	—	—
.088	13.0	15.0	.052	.045	10.0	13.1	.068	.052	12.5	14.0	.055	.049	—	—	—	—
.103	8.0	10.9	.076	.056	7.7	9.2	.079	.067	9.0	10.9	.068	.056	12.0	—	.051	—
.074	8.7	14.0	.072	.045	8.2	13.2	.077	.048	9.0	14.2	.070	.044	12.9	—	.049	—
.093	10.3	13.6	.072	.054	9.5	11.9	.078	.062	10.8	14.0	.068	.053	—	—	—	—
.095	9.7	12.5	.059	.045	8.0	9.2	.071	.062	9.9	11.5	.057	.050	11.5	—	.050	—
.089	11.0	14.0	.061	.048	9.5	13.2	.071	.050	10.8	14.0	.062	.048	—	—	—	—
.097	10.3	12.5	.063	.052	8.7	10.5	.075	.062	10.8	12.9	.060	.050	13.0	—	.050	—
.102	10.5	12.5	.064	.054	8.8	10.5	.076	.064	10.5	13.0	.064	.052	—	—	—	—
.092	9.0	13.5	.071	.047	8.0	12.0	.080	.053	9.0	14.0	.071	.046	—	—	—	—
.102	10.3	12.7	.064	.052	8.0	11.1	.083	.060	10.5	12.2	.063	.054	—	—	—	—
.092	9.3	12.5	.065	.048	8.0	10.1	.075	.060	9.9	12.0	.061	.050	—	—	—	—
.100	13.0	—	.054	—	11.5	12.5	.061	.056	12.0	13.9	.058	.050				
.103	13.0	—	.055	—	12.0	12.9	.060	.056	11.9	13.8	.060	.052				
.093	9.8	—	.081	—	9.0	14.2	.088	.056	10.0	14.5	.079	.054				
.104	10.8	13.5	.072	.058	10.6	12.5	.073	.062	12.0	14.0	.065	.056				
.117	10.5	12.5	.067	.056	8.5	10.2	.082	.069	10.3	11.5	.068	.061				
.099	10.5	13.5	.070	.055	9.6	12.0	.077	.061	9.9	14.0	.075	.053				
.097	14.0		.053		10.8	13.0	.068	.057	12.0	14.0	.062	.053				
.117	10.5	12.5	.072	.061	8.5	10.0	.089	.076	10.7	12.0	.071	.063				
.129	9.7	11.3	.078	.067	8.5	9.5	.089	.080	9.9	11.0	.077	.069				
.116	11.3	13.5	.077	.065	9.5	12.0	.092	.072	12.0	14.0	.072	.063				
.098	—	—	—	—		—	—	—	—	—	—	—				
.104	13.2	—	.061	—	11.5	12.3	.070	.066	12.0	13.5	.068	.060				
.098	13.3	—	.066	—	12.8	—	.068	—	13.9	—	.063	—				
.095	14.3	—	.067	—	10.9	—	.087	—	13.9	—	.068	—				
.104	12.5	—	.070	—	10.9	12.3	.081	.071	12.9	15.0	.068	.059				
.108	10.8	13.6	.075	.060	9.9	13.0	.081	.062	10.8	14.0	.075	.058				
.090	—	—	—	—	12.0	14.1	.067	.058	12.9	—	.063	—				
.100	13.3	—	.068	—	10.0	14.1	.090	.064	12.9	15.1	.070	.060				
.089	11.8	—	.072	—	9.0	14.3	.094	.059	12.0	—	.071	—				
.108	10.8	13.5	.078	.062	9.0	12.1	.093	.069	10.8	15.0	.078	.056				
.123	12.3	—	.078	—	9.9	13.1	.096	.073	12.9	—	.074	—				
.108																
.114																
—																
.126																
—																
—																
—																
—																
—																
.111																
—																
—																
—																

Col. 1 - The identifying number of the specimen

When the first digit is:	5	4	3	2	1
The respective gauge is:	14-1/2	12-1/2	11	9	6

The second and third digits indicate the zinc coating weight in code and identify the individual specimen.

Col. 2 - The zinc coating weight, oz. per sq. ft. of surface. It is the average of all stripping test determinations.
Col. 3 - The percent iron in the coating.
Col. 4 - Code for the type of galvanizing:
TH = Tight Wiped Hot Dip.
CH = Charcoal Wiped Hot Dip
HT = Heat Treated - Hot Dip
EG = Electro Galvanized
SP = Special Double Hot Dip
Col. 5 - The years of exposure until first rust.
Col. 6 - The years of exposure until 100% rusted.
Col. 7 - Loss of zinc, oz. per sq. ft. per year calculated as Coating weight Col. 2 divided by years to 1R Col. 5
Col. 8 - Loss of zinc oz. per sq. ft. per year Calculated as Coating weight Col. 2 divided by years to 100R Col. 6.

Blank spaces are for specimens not yet sufficiently rusted for determinations.

weight as determined by stripping tests is given in the published reports, but these reports do not state how the zinc coating was applied. The generally used, commercial processes of galvanizing, in use at the start of these tests, are:

Tight-Wiped Hot-Dip.—The wire after its bath of molten zinc is wiped with asbestos pads to smooth the coating and wipe off some of the zinc. This treatment generally yields a low weight smooth coating rather high in iron content.

Charcoal-Wiped Hot-Dip.—The wire after its bath of molten zinc is passed through a charcoal bed. This process yields a heavier coating than the tight-wiped process, though ordinarily not so uniform because the charcoal has little wiping action. The iron content of the coating is lower than in tight-wiped coatings, mostly because of the greater amount of zinc left on, and is lower than for the heat-treated coating, which by prolonged heating promotes the formation of zinc-iron alloy.

Heat-Treated. –After the wire leaves the molten zinc the medium weight coating is smoothed by heating in a furnace or by a flame. The prolonged heating is conducive to the formation of a zinc-iron alloy throughout the coating, and the resultant coating is higher in iron content than is the same weight charcoal-wiped coating.

Electrogalvanized.—The zinc is electroplated on the wire; no smoothing of the coating is required. The resultant coating is almost pure zinc and is extremely low in iron content.

Special Double-Dip.—At the time this test was started it was difficult to get coatings much in excess of 1 oz per sq ft on wires by any of the usual hot-dip galvanizing processes. Special double-dip processes produced test specimens in coating weights above 1½ oz per sq ft.

All these processes are not generally used in all ranges of coating weight. For low weights of coating the flexible tight-wiped hot-dip process (for control of the zinc coating weight) is almost universally used. In the heavier coating weight range all processes except tight-wiped are used; however, the hot-dip processes have limitations imposed by speed, uniformity, brittleness and adherence.

By studying the micrographs, the analyses of the coatings, and the weights of coating, a classification for each galvanized specimen was made. The electrogalvanized wires were easily picked out because of the general appearance of their micrographs and the absence of iron in their coatings. In some cases the micrographs clearly indicate the type of treatment, but such factors as chemical composition of the steel and of the zinc, temperature of the bath, and length of time in the zinc bath all influence the microstructure and formation of zinc-iron alloy and therefore the other classifications were not so easily determined. In Tables I, II, and III the type of galvanizing believed to have been used is noted as one of the five types discussed above.

Corrosion Rate:

At inspections, some made semiannually and some made annually, records were made of the years of exposure until the appearance of rust and also the years of exposure until the specimen was 100 per cent rust covered. These data for each specimen are shown in Table II and are shown as averages for various coating weight groups in Table III. These same averages are shown graphically in Fig. 1. In weight loss tests, which involved specimens from nine wire lots exposed for four different periods at each of three sites, the term loss of zinc oz per sq ft per yr was used to compare data. The weight loss specimens were weighed before and after exposure, the difference in weight being the zinc lost, which when divided by the exposure time gave the rate of zinc loss. It is desirable to have some such readily comparable

TABLE III.- AVERAGES - YEARS UNTIL RUST AND CORROSION RATE OF ZINC COATED STEEL WIRES AT VARIOUS SITES.

Coating Weight Groups	No. in Group	Pittsburgh		Sandy Hook		Bridgeport		State College		Lafayette		Ithaca		Ames	
		Observed Years of Exposure to 1R and to 100R													
		1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R
0.20 to 0.30 Avg. 0.28	6	0.8	1.3	1.7	2.8	2.1	2.8	5.1	6.2	4.6	5.6	5.6	6.2	6.3	7.5
0.25 to 0.35 Avg. 0.30	8	0.9	1.4	2.5	3.2	2.3	3.5	4.9	6.7	4.8	6.3	5.6	7.3	6.9	9.3
0.35 to 0.45 Avg. 0.38	7	1.5	2.0	2.8	3.7	2.9	3.7	6.6	8.4	5.5	6.8	6.7	8.3	8.4	11.4
0.45 to 0.55 Avg. 0.47	10	1.8	2.5	3.8	5.2	3.8	5.6	7.9	10.3	7.1	9.2	8.3	10.4	10.7	-
0.50 to 0.60 Avg. 0.56	5	1.7	2.1	4.7	6.0	4.7	5.7	9.5	11.7	8.5	10.0	9.3	11.2	12.1	-
0.60 to 0.70 Avg. 0.65	12	2.2	2.8	5.6	6.8	5.4	7.1	10.2	13.2	8.8	11.4	10.4	13.0	-	-
0.70 to 0.85 Avg. 0.75	10	2.1	2.8	5.9	7.2	5.7	7.1	11.3	-	9.8	11.9	11.1	13.3	-	-
0.80 to 1.00 Avg. 0.88	11	2.7	3.3	7.1	8.7	6.8	8.9	-	-	-	-	-	-	-	-
1.20 to 1.35 Avg. 1.28	2	3.7	5.0	9.4	11.5	9.0	11.5	-	-	-	-	-	-	-	-
1.60 to 1.80 Avg. 1.76	11	4.2	5.6	-	-	-	-	-	-	-	-	-	-	-	-
2.70 to 3.00 Avg. 2.89	3	7.3	8.4	-	-	-	-	-	-	-	-	-	-	-	-

Coating Weight Groups		Calculated Corrosion Rates													
		Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}	Z_{1R}	Z_{100R}
0.20 to 0.30 Avg. 0.28	6	.379	.220	.155	.099	.137	.097	.055	.045	.061	.050	.052	.045	.045	.038
0.25 to 0.35 Avg. 0.30	8	.374	.220	.129	.094	.137	.099	.064	.045	.061	.048	.053	.042	.044	.033
0.35 to 0.45 Avg. 0.38	7	.264	.193	.135	.104	.132	.088	.058	.046	.070	.056	.057	.047	.046	.034
0.45 to 0.55 Avg. 0.47	10	.268	.193	.126	.092	.135	.105	.060	.045	.066	.051	.056	.045	.044	.031
0.50 to 0.60 Avg. 0.56	5	.346	.279	.120	.095	.123	.085	.059	.049	.067	.056	.060	.050	.046	.042*
0.60 to 0.70 Avg. 0.65	12	.306	.237	.120	.097	.119	.098	.065	.049	.075	.058	.063	.050	.050*	-
0.70 to 0.85 Avg. 0.75	10	.372	.280	.129	.107	.123	.093	.068	.060	.078	.064	.069	.057	-	-
0.80 to 1.00 Avg. 0.88	11	.335	.271	.124	.102	.134	.108	.071	.061*	.083	.065*	.070	.058*	-	-
1.20 to 1.35 Avg. 1.28	2	.345	.262	.136	.110	.132	.102	-	-	-	-	-	-	-	-
1.60 to 1.80 Avg. 1.76	11	.429	.315	.160*	-	.156	.118*	-	-	-	-	-	-	-	-
2.70 to 3.00 Avg. 2.89	3	.392	.340	-	-	-	-	-	-	-	-	-	-	-	-
Average of all Wires	85	.343	.252	.131	.099	.133	.098	.063	.049	.071	.056	.061	.049	.045	.035

Wire Gauge Groups															
500's -14-1/2 Ga. Dia. .076"	14	.373	.271	.140	.104	.133	.105	.060	.049	.070	.058	.060	.051	.045	.038
400's - 12-1/2 Ga. Dia. .098"	17	.338	.248	.131	.101	.135	.104	.062	.050	.070	.058	.061	.051	.046	.035
300's - 11 Ga. Dia. .120"	19	.335	.250	.124	.097	.130	.092	.064	.048	.071	.056	.060	.049	.045	.031
200's - 9 Ga. Dia. .148"	24	.330	.255	.132	.096	.133	.093	.063	.047	.072	.054	.060	.046	.040	.033
100's - 6 Ga. Dia. .192"	11	.355	.228	.135	.100	.135	.094	.065	.048	.075	.056	.064	.048	.046	.031
Galvanizing Type Groups															
Tight WHD 0.25-0.54 oz./ft.^{2}	27	.327	.210	.134	.095	.131	.092	.058	.045	.064	.050	.054	.044	.044	.034
Charcoal WHD 0.60-1.35 "	20	.355	.274	.143	.115	.132	.100	.069	.054	.079	.062	.068	.040	.050	.046
Heat Treat HD 0.38-0.96 "	16	.280	.211	.136	.107	.134	.103	.068	.052	.080	.063	.066	.053	.055	.035
Electro-Med. 0.57-1.05 "	8	.368	.301	.102	.086	.110	.096	.055	.045	.063	.055	.058	.051	.046	.044
Electro-Heavy 1.69-2.80 "	7	.381	.336	-	-	-	-	-	-	-	-	-	-	-	-
Special HD 1.50-3.00 "	7	.461	.305	-	-	-	-	-	-	-	-	-	-	-	-
Iron Content Groups															
8.0% to 9.2%	11	.257	.179	.132	.094	.126	.091	.058	.044	.062	.050	.054	.044	.043	.031
7.0% to 7.9%	14	.280	.207	.128	.099	.129	.097	.060	.047	.069	.054	.058	.047	.044	.034
6.0% to 6.9%	21	.337	.238	.138	.104	.138	.101	.066	.052	.080	.062	.063	.049	.048	.037
5.0% to 5.9%	9	.369	.279	.128	.100	.130	.095	.070	.053	.074	.059	.067	.052	.049	.042
3.0% to 4.9%	8	.362	.266	.134	.101	.132	.100	.068	.052	.076	.057	.066	.052	-	-
0.5% to 1.6%	7	.461	.305	-	-	-	-	-	-	-	-	-	-	-	-
Less than 0.15%	15	.374	.310	.102	.086	.118	.099	.055	.045	.063	.055	.058	.051	.046	.044

Data from group,* incomplete.

term for the mass of data from the inspection reports.

It seemed logical that rust would not appear on a wire until the zinc had gone but would appear very shortly thereafter. If for each specimen the zinc coating weight (oz per sq ft) is divided by the number of years of exposure before first rust was observed, a value, Z_{1R}, designated corrosion rate, is obtained. Corrosion rate is the rate of loss of zinc oz per sq ft per yr literally when wires with zinc coating weight show zero life to first rust. If for any reason the zero weight coating shows an appreciable life, then the corrosion rate would have to be corrected to truly represent loss of zinc.

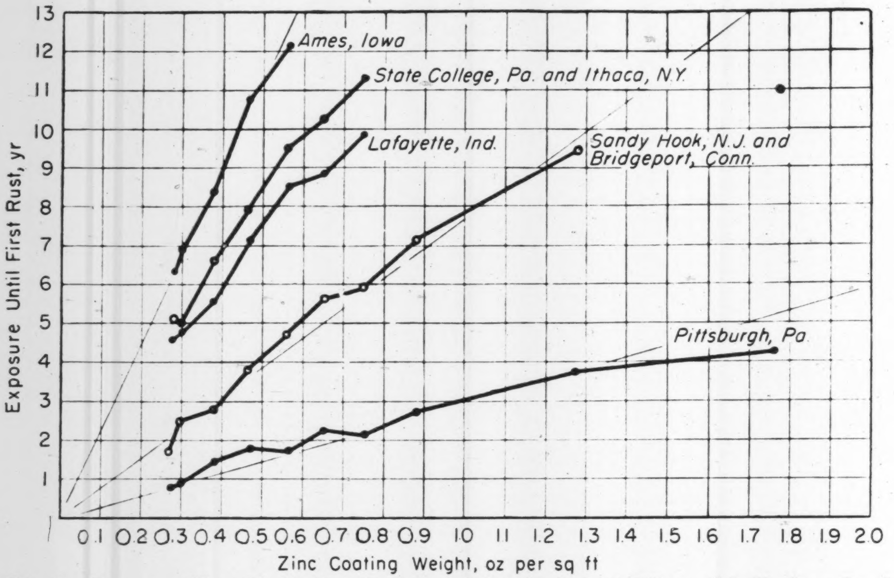

FIG. 1.—Exposure Time Until First Rust for Galvanized Steel Wires with Various Coating Weights.

The corrosion rate by derivation represents for each point a straight line function to zero origin. To the extent that coating weight *versus* time to rust is not a straight line relation to the point of origin or is not a straight line, the corrosion rate loses range for true comparability. The relation between coating weight and time until first rust, plotted in Fig. 1, appears to be a sufficiently straight line through the point of origin so that corrosion rate may be used throughout the range of data as a comparable figure to bring out major differences in exposure sites, galvanizing types, or wire gages.

As a preliminary test of the method, the inspection data observed for wires from the same lots as the nine wires that were in the weight loss tests were analyzed, and the weight loss data and calculated corrosion rate are shown in Table I for all sites for which data from weight loss tests are available. The corrosion rate was calculated to first rust Z_{1R} and to Z_{100R}. The spread between the two values for corrosion rate is to a certain extent the measure of the unevenness of the coating, but is more likely due to other obscure factors invariably associated with corrosion. The closer agreement between Z_{1R} than Z_{100R} and the weight loss data indicate that Z_{1R} is a better value to use for corrosion rate. It is not to be expected that the figures would agree perfectly. Some of the more obvious reasons why variations in the data are to be expected are:

Exposure Unit.—This is a product of time and atmosphere. Although time is constant enough the atmosphere varies. Industrial activity, winter and summer, the usual exceptional hot, cold, and wet spells all have an effect which can be quite pronounced over short periods.

Extrapolations of 1R and 100R.—Some samples went from 0R to 100R between inspections, making accurate extrapolation impossible. In nearly all cases some extrapolation was necessary to arrive at 1R or 100R.

Variation in Coating.—The coating weight chosen as representative was the average of all tests on unfabricated wire, barbed wire, fence, etc. from the same wire lots. In some cases, there was a considerable spread between the average coat and the coat as determined on unfabricated wire alone.

Determination of R.—Inspectors did not always agree on 1 per cent R, 100 per cent R, or an intermediate per cent R. Results reported are the average of reports of the inspections group which frequently varied in personnel at different inspections.

While these factors have appreciable effect on the data for individual wires presented in Table II, they should wash out when groups of wires are considered. The calculations were then made for all the specimens which have shown sufficient rusting to data and the corrosion dates so derived are shown in Table II. Figure 2 shows the spread of the calculated values for each site. Table III, compiled from data in Table II, shows the group averages for years of exposure until beginning of rust and complete rust and also the corrosion rate. Table III is arranged to show these averages for coating weight groups, wire gages, galvanizing types, and groupings based on iron content in the coating. The coating weight groups are as established originally in the test to cover galvanized

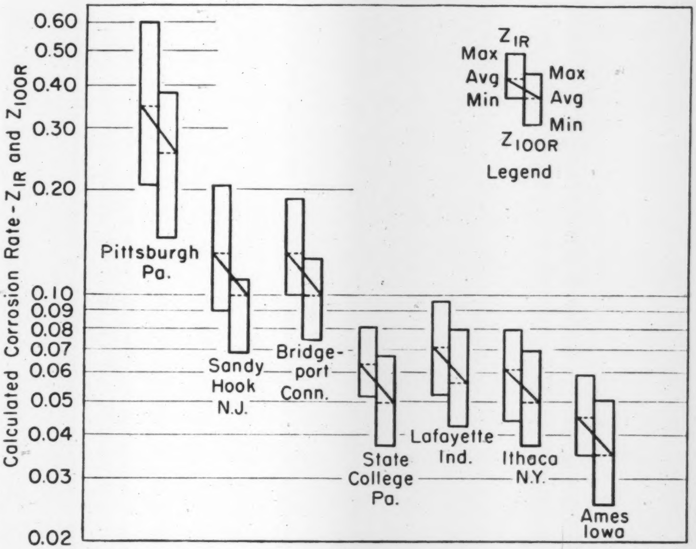

FIG. 2.—Range of Calculated Corrosion Rates at Various Sites.

wires supplied under commercial specifications at that time.

In Table III and Fig. 1 can be found the values for estimating service life of any known weight of coating, at any locality the general corrosiveness of which is known sufficiently to place it properly with regard to the exposure sites in this test. The first part of the table will serve to approximate this service life directly in years. The over-all average corrosion rate provides another way to estimate life for a known coating weight because the coating weight need only be divided by the approximate Z_{1R} value (for the locality in question) to obtain the years of service life to first rust.

Table III gives the calculations based on both the time to beginning of rust and the time to complete rust coverage. It is felt that for estimating purposes the Z_{1R} values (to beginning of rust) should be used. In later discussions of tensile strength loss the time to first rust is also used. It can, of course, be argued that any other value, 5, 10, or 50 per cent would be as good a jumping off point. The presentation of the data for both Z_{1R} and Z_{100R} permits selection of starting point. The service life of the zinc coating appears to be in general in direct proportion to the weight of the coating, and the corrosion rates from Table III are: Pittsburgh, 0.34, Sandy Hook, 0.13, Bridgeport 0.13, State College 0.06, Lafayette 0.007, Ithaca 0.06, Ames 0.04. The other remaining test sites will have values lower than 0.04.

The gage of the wire, within the test limits, seems to have no effect on the rate of zinc loss judging from the summary for gage groups in Table III; however, in Table I there is an indication if judgment is based solely on the weight loss data of column 5, that wires of lighter gages lose coating somewhat faster than wires of heavier gages. For any one location the values are almost identical for all the wire gages under test.

As shown in the summary of galvanizing types, Table III, the special heavy weight hot-dip specimens at Pittsburgh did not do as well as the other specimens. Otherwise there appears to be no significant difference in the corrosion rates of the different types of galvanizing when all exposure sites are considered. However, minor differences at specific exposure sites are shown in the corrosion rates as calculated. The electrogalvanized specimens had a higher corrosion rate than did the hot-dipped specimens at Pittsburgh but had a lower corrosion rate at Sandy Hook than all other types and were about average at other locations. The heat-treated specimens had the lowest corrosion rate at Pittsburgh. At all exposure sites the electrogalvanized specimens had a much shorter time spread between 1R and 100R than any of the other specimens. The electrogalvanized specimens went from gray to rust without any intermediate yellowing stage. The heat-treated specimens and others with high iron content in the coating had a prolonged discolored period before actual rusting of the base metal began.

The effect of varying the per cent iron content of the zinc coating is also shown in Table III. The beneficial effect of a zinc-iron alloy in the coating is quite noticeable at the Pittsburgh site. At Sandy Hook the per cent of iron or zinc-alloy shows little or no effect on the rate of corrosion.

Strand, fencing, and barbed wire are also exposed in these tests. Strand is at all locations; chain link fences are at all but three rural locations. Farm field fences and barbed wire are at all locations except Pittsburgh, Sandy Hook, and Bridgeport.

Barbed wire in regard to rusting proceeds so nearly parallel to the unfabricated wire that no more need be said about it except that the cut barbs show rust a year or two ahead of the wire. The other items have conditions in their make-up or methods of exposure which make direct comparisons with the unfabricated wires difficult.

Galvanized steel strands with coating weights as low as 0.69 oz per sq ft have shown no rusting except at the most corrosive sites such as Pittsburgh, Sandy Hook, and Bridgeport. Even at Sandy Hook and at Bridgeport these lowest coating weight specimens are not yet 100 per cent rust covered. In Table IV below are shown the observed rusting data and the calculated corrosion rates. The calculated average corrosion rates are 0.22 for Pittsburgh, 0.10 for Sandy Hook, and 0.09 for Bridgeport. These are somewhat lower than the 0.34, 0.13, 0.13 values determined in comparable manner for the unfabricated wires at the same respective sites. Evidently the wires comprising a strand protect each other to some extent by their proximity. Rust on galvanized strand first appears at the high spots of the individual outer wires and grades off to the points where the outer wires are tangent. Even on strands where rusting is well advanced and appears to cover the specimen, examination has shown that there is negligible corrosion on the core wire and on the inner surfaces of the outer wires. Consequently very little reduction in strength can have taken place. The data obtained on the unfabricated wires which are the major portion of this test are therefore not directly applicable to strand.

TABLE IV.—GALVANIZED STEEL STRAND.

Strand	Coating, oz per sq ft	Pittsburgh		Sandy Hook		Bridgeport	
		Years to 1R	Coat ÷ yr 1R	Years to 1R	Coat ÷ yr 1R	Years to 1R	Coat ÷ yr 11R
No. 345	0.69	3.9	0.18	8.9	0.09	8.9	0.08
No. 346	0.88	4.5	0.19	10.0	0.09	10.9	0.08
No. 347	0.87	3.9	0.22	10.0	0.09	10.4	0.08
No. 348	0.93	3.9	0.24	8.9	0.10	9.3	0.10
No. 360	1.10	4.9	0.22	13.4	0.08	11.0	0.10
No. 361	1.17	4.9	0.24	11.9	0.10	13.5	0.09
No. 362	1.03	4.9	0.21	10.5	0.10	10.9	0.10
No. 365	1.51	6.9	0.22	...	...	13.5	0.11
No. 366	1.39	5.0	0.18	13.5	0.10	...	...
No. 367	1.32	6.0	0.22	11.9	0.11	13.4	0.10
No. 371	1.71	6.0	0.28	...	...	...	...
No. 375	2.47	8.5	0.29	...	...	...	...
Average	...	...	0.22	...	0.10	...	0.09

Chain link fence at Pittsburgh, Sandy Hook, and Bridgeport has rusted to the point where the data warrant some study. In Table V are shown the time to beginning of rust and the calculated rate of zinc loss. Specimens with an *E* number were galvanized before weaving, those with an *H* number were galvanized after weaving. The average corrosion rates are 0.40 for Pittsburgh, 0.18 for Sandy Hook, and 0.16 for Bridgeport. These are all slightly higher than the comparable determinations of 0.34, 0.13, and 0.13 for unfabricated wires. If, however, the results from only the chain link fences galvanized before weaving are averaged, the rates are 0.32, 0.15, and 0.13 for the respective sites. Specimens of wire from chain link fence galvanized before weaving were stripped

TABLE V.—CHAIN LINK FENCE.

Chain Link Fence	Coating, oz per sq ft	Pittsburgh		Sandy Hook		Bridgeport	
		Years to 1R	Coat ÷ yr 1R	Years to 1R	Coat ÷ yr 1R	Years to 1R	Coat ÷ yr 1R
No. E280	0.29	1.3	0.22	1.9	0.15	2.4	0.12
No. E281	0.52	1.8	0.29	2.9	0.18	3.4	0.15
No. E282	0.37	1.4	0.26	1.9	0.19	2.9	0.13
No. E185	1.22	3.9	0.31	8.4	0.14	8.9	0.14
No. E285	1.13	3.6	0.31	8.4	0.13	8.9	0.13
No. E289	1.40	4.3	0.32	11.9	0.12	13.4	0.11
No. E290	2.92	3.9	0.39	...	...	...	...
No. E291	2.09	3.6	0.38	...	...	...	...
No. H280	1.60	2.9	0.55	7.9	0.20	8.5	0.19
No. H185	1.83	3.9	0.47	8.5	0.22	9.0	0.20
No. H186	1.60	3.9	0.41	9.9	0.16	10.0	0.16
No. H187	1.61	3.9	0.41	8.9	0.18	10.0	0.16
No. H188	1.55	2.9	0.53	8.5	0.18	8.5	0.18
No. H285	1.36	3.7	0.37	7.9	0.17	9.5	0.14
No. H286	1.97	3.9	0.50	7.9	0.25	9.9	0.20
No. H287	1.46	3.5	0.42	7.9	0.18	8.6	0.17
No. H288	1.74	3.9	0.45	10.4	0.17	10.4	0.17
No. H290	4.21	7.6	0.55	...	...	...	...
Average	...	...	0.40	...	0.18	...	0.16

TABLE V I - LOSS OF TENSILE STRENGTH

	Pittsburgh, Pa.				Sandy Hook, N. J.				Bridgeport, Conn.				State College, Pa.			
Wire Lot Number*	Exp. First Rust Yrs.	Exp. Since 1R Yrs.	Tensile Strength Loss %	Tensile Strength Loss %/Yr.	Exp. First Rust Yrs.	Exp. Since 1R Yrs.	Tensile Strength Loss %	Tensile Strength Loss %/Yr.	Exp. First Rust Yrs.	Exp. Since 1R Yrs.	Tensile Strength Loss %	Tensile Strength Loss %/Yr.	Exp. First Rust Yrs.	Exp. Since 1R Yrs.	Tensile Strength Loss %	Tensile Strength Loss %/Yr.
+ 501 a	0.0	5.5	87.0	16	0.0	6.9	58.0	8	0.0	10.4	46.0	4	0.0	14.3	52.0	4
+ 506	0.0	5.5	82.7	15	0.0	6.9	56.8	8	0.0	10.4	46.0	4	0.0	14.3	55.8	4
+ 507	0.0	5.5	84.9	15	0.0	6.9	68.9	10	0.0	10.4	48.0	5	0.0	14.3	56.8	4
510	1.2	4.7	65.0	14	1.7	8.6	60.0	7	2.5	10.0	41.0	4	5.7	8.6	32.0	4
511	0.6	5.3	79.0	14	1.7	8.6	65.0	8	1.8	10.7	43.8	4	4.7	9.6	40.4	4
512	0.5	5.4	83.0	15	1.5	8.8	63.0	7	1.6	10.9	44.7	4	4.5	9.8	37.0	4
520	1.2	5.7	71.5	12	2.7	9.7	57.2	6	2.5	10.0	25.0	3	6.3	8.0	14.3	2
521	1.7	5.2	75.9	14	2.9	9.5	66.7	7	3.4	9.1	33.3	4	6.8	7.5	20.3	3
522	1.4	5.5	79.7	14	2.9	9.5	68.0	7	3.4	9.1	36.0	4	7.5	6.8	25.0	4
530	1.2	5.7	80.7	14	2.9	11.5	71.0	6	5.4	7.0	41.0	6	11.3	3.0	20.9	7
531	1.4	5.5	79.8	14	4.7	9.7	83.0	9	4.7	7.7	38.0	5	9.0	5.3	17.7	3
540	1.8	5.6	80.0	14	5.9	8.5	73.5	9	6.2	6.2	25.0	4				
541	2.6	4.9	75.7	15	5.4	9.0	72.9	8	4.9	7.5	27.1	4				
542	1.6	5.8	77.4	13	5.5	8.9	77.5	9	5.5	7.0	33.3	5				
543	1.8	5.6	75.0	13	5.9	8.5	75.0	9	5.9	6.5	26.6	4				
551	4.5	3.4	77.8	23												
552	4.9	4.5	77.4	17												
+ 400 ab	0.0	5.9	54.2	9	0.0	11.4	53.8	5	0.0	12.5	27.1	2	0.0	14.3	25.0	2
+ 401 a	0.0	5.9	65.6	10	0.0	11.4	60.7	5	0.0	12.5	33.3	3	0.0	14.3	32.4	2
+ 405	0.0	5.9	56.8	9	0.0	11.4	55.4	5	0.0	12.5	33.0	3	0.0	14.3	32.0	2
+ 406 b	0.0	5.9	44.7	7	0.0	11.4	45.6	4	0.0	12.5	23.4	2	0.0	14.3	25.6	2
410	0.6	5.3	51.7	10	1.8	10.6	43.8	4	1.8	10.6	22.8	2	4.5	9.8	20.2	2
411	0.8	5.1	45.5	9	1.8	10.6	41.4	4	2.3	10.1	22.0	2	5.5	8.8	18.2	2
412	1.2	4.7	40.4	9	2.5	10.0	42.2	4	2.5	10.0	22.9	2	5.7	8.6	18.7	2
421	1.6	5.3	55.2	10	2.8	11.6	60.7	5	2.7	11.7	29.8	3	5.8	8.5	16.0	2
422	1.4	4.5	34.0	8	2.9	11.5	49.0	4	2.7	11.7	27.0	2	6.8	7.5	10.0	1
423	1.2	4.7	40.0	9	2.7	9.5	34.0	4	2.5	11.9	18.7	2	5.8	8.5	13.8	2
430	2.6	5.3	56.5	11	4.4	10.0	55.2	6	4.8	9.6	26.2	3	8.7	5.6	12.8	2
431	1.6	6.3	59.1	9	3.7	10.7	54.0	5	3.5	10.9	33.6	3	7.7	6.6	21.0	3
432	1.6	6.3	62.7	10	6.5	7.9	43.2	5	5.4	9.0	26.5	3	11.0	3.3	6.9	2
440	2.6	5.3	63.5	12	4.7	9.7	55.1	6	4.8	9.6	22.9	2				
441	1.9	6.0	63.5	11	6.5	7.9	50.0	6	5.9	8.5	28.0	3				
442	2.0	5.9	63.9	11	7.4	7.0	48.0	7	6.3	8.1	24.6	3				
443	1.9	6.0	60.6	10	5.9	8.5	58.0	7	5.8	8.6	26.0	3				
444	2.7	5.2	57.0	11	5.7	8.7	46.5	5	5.6	8.8	16.6	2				
495	1.9	5.0	57.7	10	5.9	8.5	47.3	6	5.9	8.5	27.4	3				
450	2.9	6.5	65.3	10												
451	4.5	4.9	50.0	10												
+ 300 ab	0.0	10.5	63.5	6	0.0	14.5	53.5	4	0.0	14.5	25.0	2	0.0	14.3	18.9	1
+ 302 a	0.0	10.5	74.5	7	0.0	14.5	52.3	4	0.0	14.5	32.3	2	0.0	14.3	28.7	2
+ 305	0.0	10.5	64.0	6	0.0	14.5	50.7	3	0.0	14.5	29.1	2	0.0	14.3	22.8	2
+ 306 b	0.0	10.5	58.5	6	0.0	14.5	44.4	3	0.0	14.5	24.0	2	0.0	14.3	16.9	1
315	0.4	11.0	73.3	7	1.6	12.8	43.9	3	1.7	12.7	22.3	2	3.6	10.6	17.1	2
316	1.2	10.3	64.7	6	2.7	11.7	35.8	3	2.5	11.6	16.4	1	5.7	8.6	11.1	1
317	1.4	8.0	40.8	5	3.7	10.7	40.3	4	2.8	11.6	25.1	2	6.8	7.5	10.7	1
325	1.7	9.7	61.5	6	3.8	10.6	33.6	3	3.9	10.5	17.8	2	7.8	6.5	7.5	1
326 a	1.4	10.1	91.4	9	3.8	10.6	42.2	4	2.9	11.5	27.2	2	6.5	7.8	10.7	1
327	1.8	9.7	70.3	8	3.8	10.6	40.1	4	3.9	10.5	23.3	2	8.0	6.3	6.8	1
329	1.8	9.7	68.7	7	3.8	10.6	41.7	4	3.8	10.6	20.2	2	6.3	8.0	8.3	1
335	1.6	9.9	68.3	7	4.9	9.6	37.1	4	5.4	6.0	15.3	2	8.0	6.3	9.6	1
336	2.7	8.7	67.2	8	4.8	9.6	40.2	4	5.4	6.0	13.5	2	10.3	4.0	7.9	2

337	2.5	9.0	70.4	8	4.8	9.6	40.2	4	5.4	6.0	15.8	2	9.7	4.6	11.1	2
338	2.0	9.5	67.3	7	7.9	6.5	32.3	5	6.7	4.7	14.8	3	12.0	2.3	0.0	0
345	2.7	9.8	74.8	8	5.9	5.5	25.3	5	5.7	3.7	5.1	1				
346	2.5	10.0	74.8	7	6.5	4.9	18.7	4	6.9	2.5	12.6	5				
347	2.6	9.9	76.8	8	7.8	3.6	16.4	5	6.9	2.5	8.1	3				
348	3.2	9.3	65.8	7	10.5	0.5	5.1	10								
350	5.1	8.2	67.2	8												
351	2.9	10.4	63.4	6												
352	3.9	9.4	63.4	7												
397	7.5	5.8	36.7	6												
+ 200 a	0.0	12.5	72.7	6	0.0	14.5	47.8	3	0.0	14.5	25.4	2	0.0	14.3	15.8	1
+ 202 a	0.0	12.5	59.7	5	0.0	14.5	38.1	3	0.0	14.5	19.8	1	0.0	14.3	15.2	1
+ 205	0.0	12.5	64.0	5	0.0	14.5	43.7	3	0.0	14.5	20.3	1	0.0	14.3	9.5	1
+ 206	0.0	12.5	56.4	5	0.0	14.5	40.2	3	0.0	14.5	22.0	2	0.0	14.3	16.9	1
215	0.6	11.9	59.1	5	1.8	8.7	26.9	3	1.8	10.7	12.8	1	3.6	10.6	4.6	-
216	1.3	11.2	50.6	5	2.5	10.0	24.5	2	2.8	9.7	11.6	1	5.7	8.6	3.9	-
217	1.0	11.4	42.1	4	2.8	9.6	22.2	2	2.7	9.8	10.2	1	5.5	8.8	0.9	-
282	1.4	6.5	34.1	5	2.8	11.6	31.4	3	2.8	11.6	18.9	2	6.7	7.6	9.8	1
225	1.9	11.4	51.4	5	3.9	10.9	30.0	3	3.9	10.5	13.9	1	8.0	6.5	7.6	1
226	1.9	11.4	46.5	4	3.9	5.5	11.7	2	3.9	10.5	14.8	1	8.7	5.6	8.3	1
227	2.5	10.8	53.4	5	4.4	10.5	32.0	3	4.4	10.0	16.2	2	8.7	5.6	8.5	1
228	1.6	11.7	47.7	4	2.9	11.5	23.1	2	3.8	10.6	12.1	1	7.8	6.5	9.3	1
235	2.6	10.7	48.2	5	5.5	8.9	40.5	4	5.7	8.7	8.6	1				
236	2.0	11.3	43.7	4	7.7	6.7	16.1	3	6.8	7.6	4.7	1				
237	1.8	11.5	51.3	4	4.4	10.0	21.2	2	4.9	9.5	16.5	2				
238	2.5	10.8	50.3	5	4.8	9.6	26.7	3	4.9	9.5	13.3	2				
239	2.6	10.7	45.5	4	5.5	8.9	21.0	2	4.4	10.0	12.5	1				
245	2.4	10.1	48.1	5	5.9	3.5	1.0	—	5.9	8.5	11.2	1				
246	2.9	9.6	48.4	5	7.9	1.5	0.3	-	6.9	7.5	10.1	1				
247	2.9	9.6	50.9	5	6.5	2.9	2.2	1	5.9	8.5	16.5	2				
248	2.1	11.2	50.4	5	7.4	2.0	1.0	-	6.8	7.6	7.9	1				
296	2.5	10.8	44.2	4	5.9	3.5	1.0	-	6.9	7.5	9.9	1				
801	3.5	9.8	52.5	5												
250	3.9	10.6	43.1	4												
251	3.9	10.6	66.0	6												
252	4.5	10.0	47.4	5												
298	7.7	5.6	26.3	5												
299	7.0	6.3	32.3	5												
+ 101 a	0.0	13.3	40.8	3	0.0	14.5	32.2	2	0.0	14.5	16.6	1	0.0	14.3	9.3	1
+ 105 a	0.0	13.3	46.5	4	0.0	14.5	29.0	2	0.0	14.5	15.9	1	0.0	14.3	5.4	—
+ 102	0.0	13.3	38.7	3	0.0	14.5	31.5	2	0.0	14.5	15.7	1	0.0	14.3	10.3	1
+ 106	0.0	13.3	33.3	3	0.0	14.5	27.7	2	0.0	14.5	10.6	1	0.0	14.3	2.5	-
115	0.6	12.7	32.6	3	1.7	4.7	8.5	2	1.7	10.8	8.5	1	3.7	10.6	0.2	-
117	0.7	12.6	29.2	2	2.5	4.0	6.1	2	2.7	9.8	7.5	1	4.7	9.6	0.7	-
125	1.4	13.1	33.2	3	3.4	11.0	20.4	2	3.7	10.7	10.6	1	7.3	7.0	0.0	-
127 a	1.7	12.8	46.7	4	3.9	10.5	19.9	3	4.0	10.4	10.4	1	8.7	9.6	0.0	-
135	2.6	11.9	32.1	3	5.9	9.0	18.6	2	4.9	9.5	10.3	1				
138	2.0	12.5	25.9	2	5.5	9.0	15.6	2	4.9	9.5	8.7	1				
139	1.9	12.6	30.5	2	4.8	9.6	18.5	2	4.9	9.5	8.4	1				
148	2.7	11.7	26.7	2	6.9	2.5	5.7	2	6.9	7.5	6.1	1				
149	2.7	11.7	27.7	2	6.8	2.6	4.2	2	6.9	7.5	7.6	1				
800	3.9	9.4	27.5	3												
151	3.9	10.6	25.1	2												

* 500 Series - 14 1/2 gauge 400 Series - 12 1/2 gauge 300 Series - 11 gauge 200 Series - 9 gauge 1 Series - 6 gauge

+ Uncoated wires. All other wires had zinc coating.

a Low copper content wires, 0.05 to 0.08 per cent copper. All other wires have about 0.25 per cent copper.

b High phosphorous content (0.05 to 0.08 per cent). All other wires under 0.02 per cent.

and tested for coating weights the same as plain wire; in the case of the fence galvanized after weaving a 12-in. square sample of the fabric was stripped and the over-all coating weight reported. In general the galvanizing after weaving resulted in a coating less smooth than the coating on the other fences, and this may account for the higher zinc loss rates prevailing for these fences, because rusting takes place at the thin spots, but reported coating weights include lumps.

Farm field fences appear to corrode at the same rate as the comparable unfabricated wires. However, because of the complexity of their make up (some fences have different wire lots for line and for stay wires and for top, intermediate or bottom line wires) it is extremely difficult to tabulate the data. Another feature which also complicates the presentation of data from these fences is the tendency of the lower part of the fence to corrode less than the upper part. This has also been observed in the case of the chain link fence, but has not complicated data presentation because on chain link fence the reported state of corrosion is that observed at eye level.

The reduction in corrosion rate on the lower part of fences is not due to the presence of grass or weeds, because these have been kept down and in some cases were nonexistent near the fence specimens. Wind movement is usually somewhat less at the ground than it is higher up. It may be that reduced vibration because of lower wind velocities, reduced number of salt or mineral particles reaching the wires because of either lower wind velocities or fewer particles in the air near the ground, all contribute to effecting a reduced corrosion rate for the part of the fence nearer the ground.

STAINLESS STEEL, COPPER-CLAD, AND LEAD-COATED SPECIMENS

Regarding the stainless steel, the copper-clad and the lead-coated specimens there is very little to say at present. The stainless chromium steels have shown discoloration and minor pitting in some cases, but the chromium-nickel steels remained bright. The copper-clad specimens show the usual copper patina in varying degrees. The lead-coated specimens all showed pin hole rusting early in the test, but much of it has been self-sealing, and in some cases, notably at Bridgeport, the pin hole rusting has almost disappeared. Tensile strength tests were made on several specimens of these different types, mostly from the Pittsburgh site, although some from Sandy Hook and from Bridgeport were included. Except in the case of the smallest gage samples at Pittsburgh, none of the specialty wires has shown any loss of tensile strength to date.

TABLE VII.—LOSS IN BREAKING STRENGTH, PER CENT PER YEAR.

Gage of Wire	14½	12½	11	9	6
Diameter, in	0.078	0.098	0.120	0.148	0.192
Cross-Section, sq in	0.0047	0.0075	0.0114	0.0172	0.0289
Pittsburgh, Pa.	15	10	7	5	3
Sandy Hook, N. J.	9	5	4	3	2
Bridgeport, Conn.	4	3	2	1	1
State College, Pa.	4	2	1	1	...

TENSION TESTS

The too general assumption that a wire completely covered with rust has very little strength left is not a correct assumption. Tensile strength tests made on wires which have rusted show that the strength of the wire once it has become 100 per cent rusted is gradually reduced in almost direct proportion to the time it is exposed, except for a high initial rate of strength loss when rusting first begins. Although in some few cases appearance may be a deciding factor, the general usefulness of a wire fence or strand depends on its strength. The rate of loss of tensile strength with exposure time of a rusted wire is considerably less than most people imagine. ASTM tests have established some values for loss of breaking strength with time and exposure that should be useful for forecasting the service life of fencing and other wire products.

TABLE VIII.—LOSS OF TENSILE STRENGTH FOR BARE STEEL WIRES.

	Pittsburgh			Sandy Hook			Bridgeport			State College		
	Exposure, yr	Strength Loss		Exposure, yr	Strength Loss		Exposure, yr	Strength Loss		Exposure, yr	Strength Loss	
		Per cent	Per cent per yr		Per cent	Per cent per yr		Per cent	Per cent per yr		Per cent	Per cent per yr
500 Series 14½ Gage	1.48	33.3	22.5	1.44	23.3	16.1	1.45	16.3	12.6	1.30	15.1	11.7
	1.94	37.2	19.2	1.90	25.0	13.2	1.91	19.3	10.1	1.76	13.0	7.4
	2.45	40.4	16.5	2.42	28.0	11.6	2.42	21.1	8.7	2.75	17.1	6.2
	2.93	47.1	16.1	2.90	33.3	11.6	3.45	25.3	8.7	5.30	26.5	5.0
	3.48	52.0	15.0	3.45	38.2	11.6	5.45	34.2	6.3	9.27	36.4	3.9
	4.50	59.4	12.7	5.45	57.6	10.6	8.45	45.9	5.5	14.30	54.9	3.8
	5.48	84.5	15.4	6.90	61.2	9.0	10.36	46.7	4.5	...	...	...
400 Series 12½ Gage	1.48	24.7	16.7	1.44	18.7	13.0	1.45	16.1	11.1	1.30	12.5	9.6
	1.94	23.4	12.0	1.90	15.1	8.0	1.91	10.9	5.7	2.28	5.1	2.2
	2.45	25.5	10.4	2.42	15.7	6.5	3.40	13.8	4.1	4.31	11.4	2.6
	2.93	32.8	11.1	3.90	28.0	7.1	5.45	20.8	3.8	9.27	21.7	2.3
	3.48	33.8	9.7	5.45	37.8	6.9	9.42	26.3	2.8	14.30	28.8	2.0
	4.92	43.6	8.8	6.90	39.6	5.8	12.50	34.2	2.7	...	...	...
	5.95	55.3	7.4	11.43	53.9	4.7	...	...	...	...	...	...
300 Series 11 Gage	1.48	20.6	14.0	1.44	14.8	10.3	1.45	11.1	7.6	1.30	9.5	7.3
	1.94	18.4	9.5	1.90	14.0	7.2	2.42	11.2	4.6	2.28	6.8	3.0
	2.45	19.8	8.1	2.90	17.0	5.8	3.91	13.5	3.4	7.30	17.7	2.4
	3.20	14.9	7.8	3.90	20.1	5.2	5.94	13.3	2.2	14.30	21.8	1.5
	4.70	32.6	7.0	5.93	23.8	4.0	14.45	28.0	1.9	...	...	...
	6.70	46.4	6.9	14.45	50.0	3.5	...	...	...	...	...	...
	10.47	65.1	6.2	...	...	...	...	...	...	...	...	...
200 Series 9 Gage	1.48	17.8	12.0									
	1.94	16.2	8.4									
	2.93	20.1	6.8									
	3.48	22.0	6.3									
	5.95	31.0	5.2									
	11.50	59.0	5.1									
	12.50	63.2	5.1									
100 Series 6 Gage	1.48	11.0	7.4									
	1.94	12.4	6.4									
	2.93	13.6	4.4									
	3.48	15.6	4.5									
	6.48	22.6	3.5									
	12.50	39.1	3.1									
	13.30	39.8	3.0									

Tension tests made on wire specimens which were exposed in groups of seven comparison samples taken from the same lot of wire. An attempt was made to remove and test the first specimen at about 10 per cent strength loss and the last specimen at about 75 per cent strength loss. The values in this table are the averages of test results determined on uncoated steel wires whose identifying numbers are shown in Table VI. Galvanized wires follow the same pattern after the galvanizing has gone.

From four of the exposure sites a total of about 1600 wires has been removed for tensile strength tests. There were seven specimens of each wire lot exposed. For the tensile strength tests it is intended that the first specimen be tested when it has lost 5 to 10 per cent of its original strength and the succeeding specimens be tested as they lose more strength so that the final or seventh test will be made when about 75 per cent of strength has been lost. The very early tests made soon after the beginning of rust gave rather high strength losses and some erratic results, but as more exposure time elapsed the successive tests showed rates of strength loss quite proportional to exposure time. Only the latest test results are shown in Table VI. On the basis of these data the average rate of loss of breaking strength, expressed as per cent of original strength lost per year of exposure after rusting begins, is shown in Table VII. As may readily be observed from Table VI, these values apply to wires exposed uncoated and also to galvanized wires after the beginning of rust.

Although in the case of the galvanized

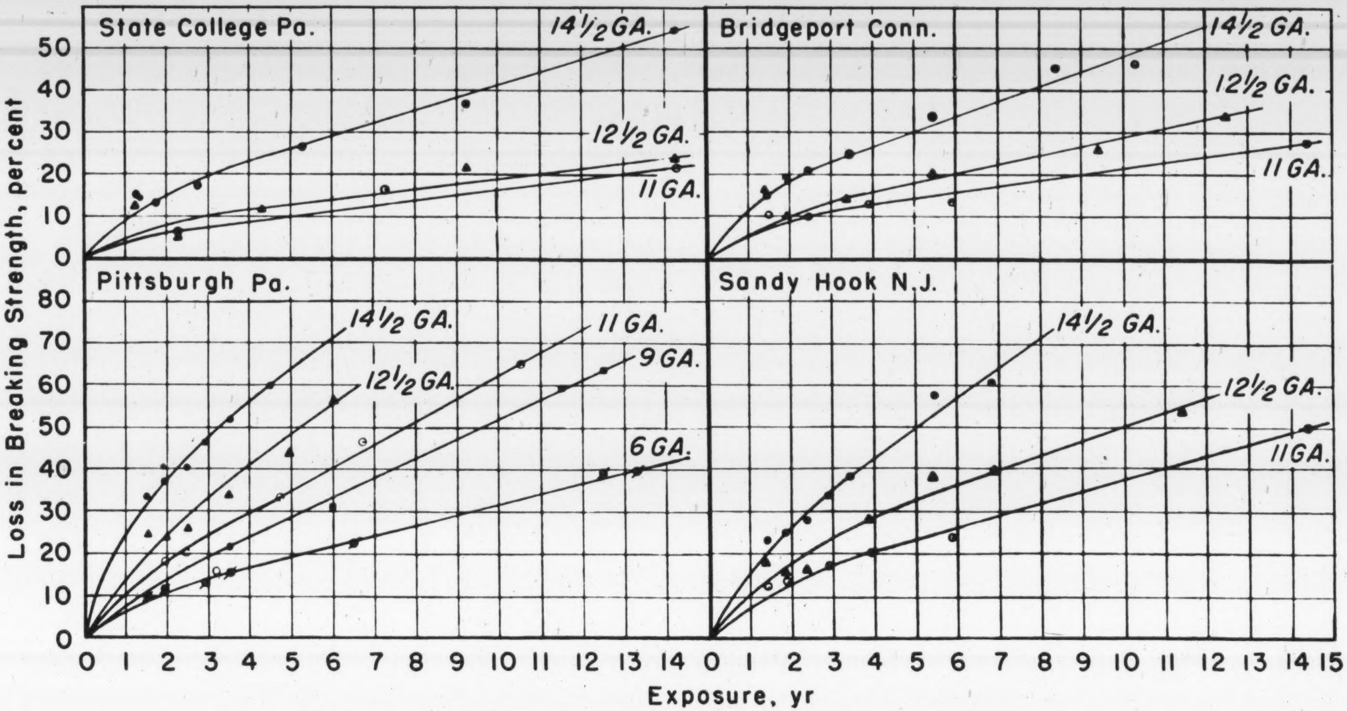

FIG. 3.—Strength Loss of Steel Wires, Uncoated Wires Exposed at Various Sites.

coatings the gage of the wire seems to make no appreciable difference in the rate of loss of zinc, the influence of wire size is quite noticeable in the matter of percentage of original tensile strength lost. The breaking strength in tension is a function of the cross-section of the wire. The cross-sectional areas of test wires of the different gages are listed in Table VII. The percentage figures for strength loss applied to these areas reduce the cross-section approximately the same amount in square inches for all gages at the same site, indicating a uniform loss in amount of steel regardless of gage size. Expressed in square inches the loss of cross-section per year of exposure is: Pittsburgh, 0.00075; Sandy Hook, 0.00045; Bridgeport, 0.00020; State College, 0.00015.

TABLE IX.—CHEMICAL ANALYSIS OF MILD STEEL WIRES.

Carbon	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Copper
0.05	0.35	0.010	0.030	0.01	0.02	0.25
1.10	0.45	0.015	0.025	0.14	0.03	0.25
0.12	0.38	0.009	0.025	0.07	0.02	0.24
0.12	0.42	*0.064*	0.024	0.03	0.02	0.23
0.12	0.46	0.018	0.035	0.18	0.02	0.22
0.25	0.46	0.016	0.037	0.18	0.05	0.22
0.12	0.38	0.012	0.020	0.10	0.02	*0.07*

The figures for loss in breaking strength, per cent per year, are reasonably well established for the smaller wires at rural locations and for wires of all gages represented in the tests at sites such as Pittsburgh, Sandy Hook, and Bridgeport where corrosion is rapid. In the case of the other rural sites, the present indications are that the rate of strength loss will approximate the values for State College. These figures for strength loss are satisfactory for use in determining the service life when the end of service life is assumed to be at around 50 per cent of original strength. The rate of strength loss is quite rapid at first, and it has been observed that stability is not well established until wires have lost around 25 to 30 per cent of the original breaking strength where the retarding effect of corrosion products is manifested. In Table VIII and Fig. 3 is shown the progress of strength loss. Table VIII and Fig. 3 are based on bare wires for simplicity, it having been observed that galvanized wires, after the loss of the zinc, behave the same as bare wires.

The wires in the test are of mild steel, about 80 to 90 per cent of them having tensile strength in the ranges of 60,000 to 100,000 psi and elongation in 10 in. exceeding 6 per cent. The extremes of tensile strength are 50,000 to 140,000 psi and the extremes of elongation being 1 to 20 per cent.

CHEMICAL ANALYSIS EFFECTS

Differences in chemical composition of the steels are shown in the typical analysis (Table IX) of several equal groups of wires comprising about 80 per cent of the test specimens.

There is no appreciable or apparent difference in the rate of strength loss which can be associated with any of the above variations in carbon or silicon content. The eight wires with highest carbon (0.25 per cent) and highest silicon (0.18 per cent), Table VI, Nos. 541, 440, 444, 337, 345, 351, 247, and 250 are evenly dispersed about the average rate of loss for their respective gages and locations. The same applies to the eleven wires with lowest carbon (0.05 per cent or less) and lowest silicon (0.01 per cent or less) Table VI, Nos. 530, 540, 432, 442, 451, 338, 348, 235, 236, 248, and 252. The effects of phosphorus and copper have been searched for with considerably more diligence than any of the other elements because of the often repeated and generally accepted statements that copper-bearing steel is more corrosion resistant than non-copper bearing steel and that phosphorus improves resistance to atmospheric corrosion.

TABLE X.—LOSS OF TENSILE STRENGTH FOR BARE STEEL WIRES.

Copper Bearing and Low Copper Content Uncoated Steel Wires Tensile Strength Tests After Exposure				Pittsburgh, Pa. 6 to 13 yr[c]		Bridgeport, Conn. 10 to 15 yr[c]		Sandy Hook, N. J. 7 to 15 yr[c]		State College, Pa. 14.3 yr		Lafayette, Ind. 10.9 yr		Ithaca, N. Y. 10.8 yr		Ames, Iowa 11.0 yr		Manhattan, Kans. 10.9 yr		College Station, Texas 10.8 yr		Davis, Calif. 10.9 yr		Santa Cruz, Calif. 10.9 yr	
				Loss in Tensile Strength (Reduction in Breaking Load), per cent and per cent per year																					
		Copper																							
Wire Lot	Gage	Class[b]	Per cent cu.	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr	%	%/yr
501	14½ 0.078 in. Diam	LC	0.07	87.0	16	46.0	4	58.0	8	52.0	4	40.0	4	28.0	3	26.0	2	7.0	1	24.0	2	15.0	1	35.0	3
506		CB	0.25	82.7	15	46.0	4	56.8	8	55.8	4	42.3	4	35.0	3	30.8	3	5.8	1	24.0	2	19.2	2	32.7	3
507		CB	0.24	84.9	15	48.0	5	68.9	10	56.8	4	42.0	4	34.5	3	31.0	3	3.4	[f]	26.1	2	18.5	2	40.4	4
400[a]	12½ 0.098 in. Diam	LC	0.08	54.2	9	27.1	2	53.8	5	25.0	2	21.9	2	14.6	1	14.6	1	1.0	[f]	9.4	1	4.2	[f]	19.7	2
401		LC	0.05	65.6	11	33.3	3	60.7	5	32.4	2	28.9	3	18.9	2	18.9	2	1.0	[f]	14.4	1	7.8	1	17.8	2
405		CB	0.24	56.8	10	33.0	3	55.4	5	32.0	2	25.8	2	19.6	2	21.7	2	0.0	[f]	13.0	1	10.3	1	18.5	2
406[a]		CB	0.23	44.7	7	23.4	2	45.6	4	25.6	2	23.4	2	14.8	1	13.8	1	0.0	[f]	8.5	1	7.5	1	14.9	1
300[a]	11 0.120 in. Diam	LC	0.08	63.5	6	25.0	2	53.5	4	18.9	1	15.5	1	7.5	1	10.8	1	0.0	[f]	7.4	1	4.7	[f]	10.1	1
302		LC	0.07	74.5	7	32.3	2	52.3	4	28.7	2	25.0	2	16.8	1	16.8	1	5.9	[f]	19.1	2	13.2	1	17.3	2
305		CB	0.24	64.0	6	29.1	2	50.7	3	22.8	2	22.1	2	12.9	1	15.2	1	1.4	[f]	12.0	1	7.4	1	13.8	1
306[a]		CB	0.22	58.5	6	24.0	2	44.4	3	16.9	1	15.5	1	7.0	1	10.5	1	0.0	[f]	8.5	1	4.9	[f]	13.4	1
200	9 0.148 in. Diam	LC	0.06	72.7	6	25.4	2	47.8	3	15.8	1	19.3	2	12.0	1	17.3	2	2.4	[f]	11.5	1	9.1	1	13.9	1
202		LC	0.07	59.7	5	19.8	1	38.1	3	15.2	1	[d]	2[e]	7.3	1	[d]	1[e]	[d]	[f]	6.1	1	9.5	1	7.9	1
205		CB	0.24	64.0	5	20.3	1	43.7	3	9.5	1	14.0	1	9.6	1	5.9	1	1.0	[f]	3.2	[f]	6.3	1	9.5	1
206		CB	0.25	56.4	5	22.0	2	40.2	3	16.9	1	17.9	2	11.5	1	12.5	1	3.4	[f]	8.5	1	8.8	1	10.8	1
101	6 0.192 in. Diam	LC	0.06	40.8	3	16.6	1	32.2	2	9.3	1	10.6	1	5.6	1	7.1	1	1.1	[f]	3.2	[f]	5.4	[f]	4.8	[f]
105		LC	0.05	46.5	4	15.9	1	29.0	2	5.4	[f]	12.7	1	7.4	1	9.4	1	0.0	[f]	8.6	1	9.1	1	8.2	1
102		CB	0.24	38.7	3	15.7	1	31.5	2	10.3	1	13.8	1	10.0	1	9.9	1	5.5	[f]	2.0	[f]	2.7	[f]	10.7	1
106		CB	0.23	33.1	3	10.6	1	27.7	2	2.5	[f]	9.2	1	6.5	1	7.1	1	0.0	[f]	4.8	[f]	3.7	[f]	5.4	[f]

[a] Rephosphorized Steel 0.05 to 0.08 per cent Phosphorous.

[b] LC Low copper—No added copper—0.05 to 0.08 per cent Copper.
CB Copper bearing—Copper added—0.22 to 0.25 per cent Copper.

[c] Wires of different gages had different exposure periods.

[d] Data missing.

[e] Data from an earlier test.

[f] Data not significant. Less than ½ per cent per yr.

	C	Mn	P	S	Si	Cr
Range of Other Elements	0.09	0.36	0.006	0.016	0.04	0.01
	0.13	0.65	0.066*	0.026	0.16	0.03

* Wire Lots 300, 306, 400, 406 only.

There are no specimens of copper-free steel in test. The distinction in these tests is between so-called copper-bearing steel with added copper to about 0.25 per cent and low copper content steel which has a natural residual copper content of about 0.05 to 0.07 per cent as a result of the scrap used. All the galvanized wires with the exception of Nos. 326 and 127 were of copper-bearing steel. These two with low copper content lost strength at the same rate as the other wires. However, a much better comparison for the effect of copper can be obtained from the uncoated wires, of which ten were copper-bearing and nine had low copper content, because the comparative uncoated wires had identical exposures whereas with the galvanized wires the exposure time used for strength loss determinations began when the individual wire started to rust. Table X has been prepared to show the strength loss data for these uncoated wires. The data do not show any appreciable or consistent corrosion resistant advantage for the 0.25 per cent copper bearing steel over the 0.05 per cent copper steel.

In the case of the rephosphorized galvanized steel wires, Table VI, Nos. 520, 422, 325, 226, 228, 239, 117, 138, and 149, the rate of strength loss was consistently less than the average rate for the respective gages and locations. There are also four uncoated wires with high phosphorus content and the data for these are shown in Table X. These four wires, Nos. 406 and 306 which are copper bearing and Nos. 400 and 300 which are not, may be compared with their respective low phosphorus mates 405, 305, 401, and 302. In every case the rephosphorized steel wires had a lower strength loss; for the 12½ gage wires the loss was only 80 per cent of that for the other wires, and for the 11 gage wires the loss was only 70 per cent of that for the other wires.

The service life of wire, in regard to strength, can be estimated for most localities by use of either Table VII or Fig. 3. The estimator must, of course, be familiar enough with corrosion in the locality under consideration to classify it within the broad general types of atmospheres included in these tests.

An effect of minor alloying is noticeable in these tests only for phosphorus. Steel wires made of rephosphorized steel (0.05 to 0.08 per cent phosphorous) lost tensile strength from corrosion only about 80 per cent as fast as other steel wires. The other effects of phosphorous, good or bad, on the other properties of steel wires is not a matter for discussion in this paper. Copper of the order of 0.25 per cent had no noticeable effect on the rate of loss of strength from corrosion in these tests. So long as the steel wires have about 0.05 per cent copper present as impurities or in other residual forms, there appears to be no advantage to adding more copper.

SUMMARY

The results to date of an atmospheric exposure test of wire and wire products, which is now in its fifteenth year, are summarized. The test, under the auspices of Committee A-5 on Corrosion of Iron and Steel has a large number of wire and wire products exposed at eleven locations spotted throughout the country. The wires are mostly galvanized steel and the discussion is predominately concerned with galvanized and bare wire and wire products.

The tests at some sites are completed or about completed, but at other sites the specimens have corroded only slightly. Completion of the tests appears to be many years away.

The data are discussed first in regard to performance of zinc coatings and each specimen is classified as to type of galvanizing. The data are secondly discussed in regard to the performance of bare wires and wire from which the zinc has been lost.

The assembled data is presented in a form suitable for determining coating life through consideration of the data on the performance of zinc coatings. It is also suitable for determining life of bare wires and zinc-coated wires on which the coating has failed. If appearance alone is considered for the wire life desired, then the performance of the coating becomes the governing factor. If, however, the wire life under consideration is to some ultimate strength level, then a combination of the data can be used to compute equivalent combinations of wire sizes and coating weights.

TABLE XI.—LOSS IN BREAKING STRENGTH, PER CENT PER YEAR.

Gage of Wire........	14½	12½	11	9	6
Pittsburgh, Pa........	15	10	7	5	3
Sandy Hook, N. J.....	9	5	4	3	2
Bridgeport, Conn......	4	3	2	1	1
State College, Pa......	4	2	1	1	...

In Table III and in Fig. 1 are the means for estimating the years of exposure before rusting of mild steel wires bearing known weight of zinc coating, at any locality of which the general corrosiveness is known sufficiently to place it properly with regard to the exposure sites in this test. Figure 1 and the first part of Table III will serve to approximate this service life directly in years. The other parts of the table give more information on corrosion rate, which is of the value derived by dividing the coating weight by the observed years of exposure until the first rust. The average corrosion rate provides a way to estimate service life for a known coating weight or to estimate coating weight required for a desired service life. It is also a handy value for comparing different exposures or different galvanizing types.

These corrosion rates for the respective sites included in the tests are:

Pittsburgh, Pa................	0.34
Sandy Hook, N. J............	0.13
Bridgeport, Conn.............	0.13
State College, Pa.............	0.06
Lafayette, Ind................	0.07
Ithaca, N. Y..................	0.06
Ames, Iowa..................	0.04

The service life of a zinc coating is in general in direct proportion to the weight of the coating and appears to be independent of the gage of the wire. There is no significant difference in the corrosion rate for different types of galvanizing although minor difference at specific exposures is noted.

The per cent loss in tensile breaking strength *versus* exposure time relation for bare steel wires and for galvanized wire after the beginning of rust is materially affected by the size of the wire. The per cent loss in strength for different gages of wire is in inverse proportion to the cross-sectional area of the wires.

In regard to minor alloying, copper in the range above 0.05 per cent does not appear to affect the strength loss; phosphorous of the order of 0.05 to 0.08 appears to slow the rate of loss.

The loss in breaking strength from the present data is shown in Table XI.

Acknowledgment:

Acknowledgment is made with gratitude for the comments and criticisms received during the preparation of the report and for the use of the liberal amount of data accumulated by the test committee during the years.

ATMOSPHERIC CORROSION OF LOW ALLOY STEELS*

By H. R. Copson[1]

In 1941 five sets of 71 low-alloy steels were exposed to the industrial atmosphere at Bayonne, N. J., and to the marine atmosphere at Block Island, R. I. Complete sets of specimens were removed at 1-, 5-, and 9-yr, partial sets at 3- and 7-yr, and a few additional specimens at irregular intervals. Some results through 3 and 5 yr were published previously (**1**, **2**).[2] The present paper gives the complete results through 9 yr. This includes weight losses, pit depths, thickness measurements, calculated pitting factors, and the weight of rust on the specimens. Detailed weight loss *versus* time curves, pit depth time curves, and weight loss composition curves are plotted.

PROCEDURE

Details of the test conditions were described previously (**1**). In brief, 4- by 6-in pickled and weighed specimens were exposed at an angle of 30 deg from the horizontal and faced south. The chemical analyses and average thicknesses were given in full in the 1948 paper (**2**), but for convenience the more important elements in the compositions are included in Figs. 1 and 2. As in the past, the steels are broken up into groups; the nature of the groups is apparent in the figures and tables.

The general procedure on removing the specimens was to weigh them both with the rust intact and after cleaning. The cleaning was done cathodically in hot inhibited sulfuric acid according to established procedures.[3] After cleaning, the maximum thickness was obtained by using flat micrometers, and then the maximum difference in level between adjacent points was determined on both surfaces by using a pointed probe attached to a dial gage (**2**). These observations were used to arrive at the pit depths and pitting factors.

RESULTS ON SPECIMENS REMOVED AT 9 YR

The 9-yr results are given in Table I and II. The condition of perforated specimens is noted as well as the approximate life of missing specimens.

An important observation is that the thickness of many specimens as measured with flat micrometers was nearly the same at 9 yr as at the start. The lowering of the surface level in the case of all the better steels was one mil or less. This means that practically all the attack was confined to the pits, and that the pit depths were of considerable importance. Unfortunately, there was more scatter in the pit depth measurements than in the weight losses. The weight losses on the surviving steels at 9 yr

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Research Laboratory, International Nickel Co., Inc., Bayonne, N. J.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1026.

[3] "Tentative Method of Total Immersion Corrosion Test of Non-Ferrous Metals," Appendix I (B 185 – 43 T) 1949 Book of ASTM Standards, Part 2, p. 794.

were equivalent to an average penetration of 2 to 16 mils or a decrease in thickness of 4 to 32 mils. The weight losses and pit depths are considered further below.

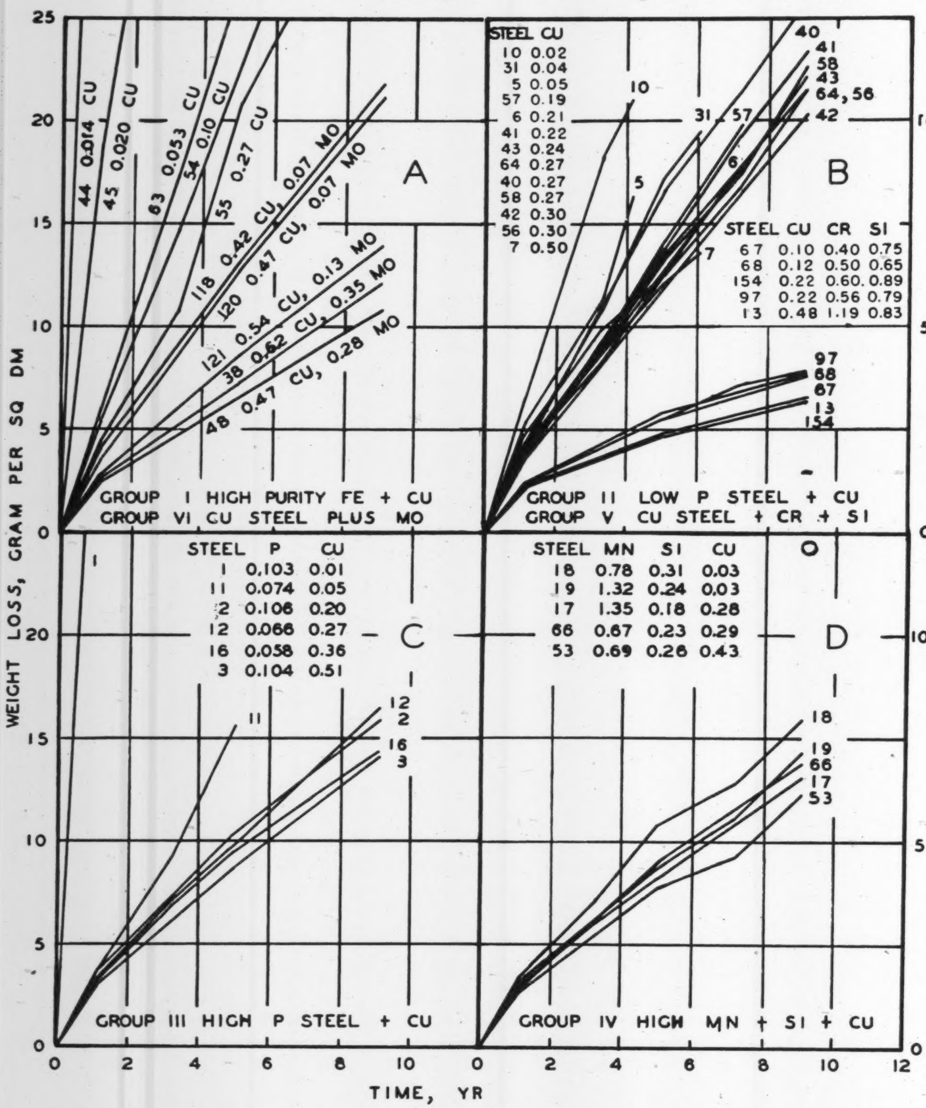

FIG. 1.—Weight Loss—Time Curves at Block Island for Steels Substantially Free of Nickel.

The amount of rust on the specimens is recorded in the tables. Most of the rust was adherent although some of the surface rust was loose. Generally the rust coating was thinner on the better steels. Comparison with earlier data at 3 yr (1) shows that at Bayonne there had been comparatively little change in the amount of rust on the specimens. At Block Island the accumulation of a little rust on the better steels and the loss of some on the poorer steels made the spread less pronounced. These observations apply to the exposure conditions and might be different in crevices and sheltered areas.

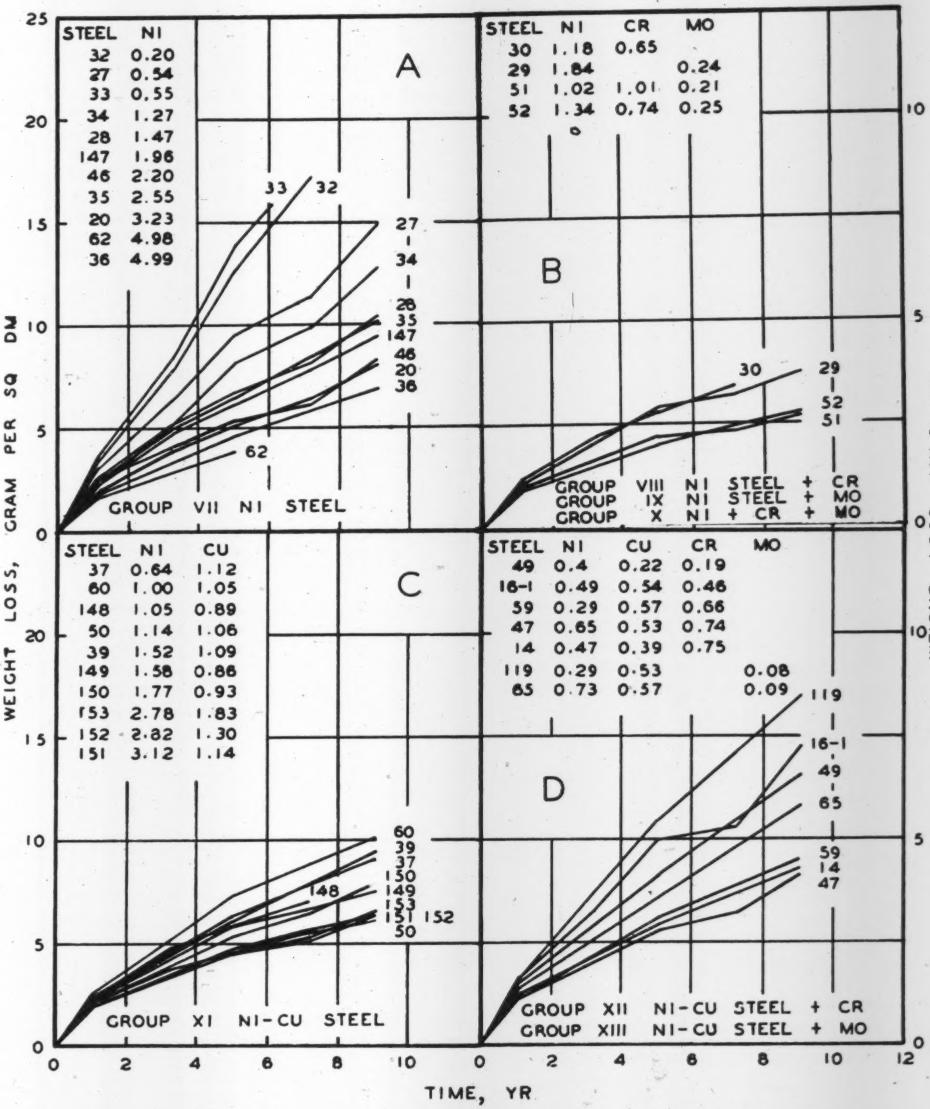

FIG. 2.—Weihgt Loss—Time Curves at Block Island for Steels Containing Nickel.

At Block Island the specimens continued to show more rapid corrosion at certain areas, namely the groundward edge, the western edge, and under insulators at the eastern edge (1). Pits were deeper and perforations more numerous in the same areas. As would be expected, the effect was most evident on the poorer steels and comparatively

TABLE I.—9-YR. RESULTS AT BLOCK ISLAND.

Exposed 5-28-41. Removed: 7-11-50
Time: 3331 days or 9.12 yr
Area: 3.15 sq dm, except 2.37 sq dm for Steels No. 67, 68, 154, and 2.63 sq dm for Steel No. 97

Material	Total Rust on Speci-mens, g	Weight Loss		Thickness, mil		Pitting, mil, Average of 4 Deepest		Average Pit Depth, mil[a]	Pitting Factor
		g per sq dm	Mdd	At Start	Max at End	Top	Bottom		
GROUP I—HIGH PURITY IRON PLUS COPPER									
No. 44				78		Corroded away at 3.3 yr			
No. 45				70		Missing after 4.1 yr			
No. 63				80		Disintegrating at 7.2 yr			
No. 54				48		Disintegrating at 6.1 yr			
No. 55				46		Disintegrating at 7.2 yr			
GROUP II—LOW PHOSPHORUS STEEL PLUS COPPER									
No. 10				51		Missing after 5.0 yr			
No. 31				32		Disintegrating at 6.1 yr			
No. 5				29		Missing after 4.1 yr			
No. 57	18.7			48		Disintegrating at 9.1 yr			
No. 6				30		Disintegrating at 7.2 yr			
No. 41	19.2	23.4	7.0	75	66	20.8	31.5	30.6	2.6
No. 43	20.3	22.2	6.6	80	74	18.0	31.3	27.6	2.5
No. 64	18.7	21.5	6.5	82	76	20.3	36.3	31.3	2.9
No. 40	20.1	25.8	7.8	63	58	5 Perforations, ⅛ in.		31.5	2.4
No. 58	19.6	22.6	6.8	61	56	20.5	28.8	27.1	2.4
No. 42	18.6	20.3	6.1	75	69	16.8	27.3	25.0	2.4
No. 56	18.0	21.5	6.4	49	44	20 Perforations, 1/16 in.			
No. 7				28		Missing after 6.1 yr			
GROUP III—HIGH-PHOSPHORUS STEEL PLUS COPPER									
No. 1				57		Corroded away at 3.3 yr			
No. 11				32		Missing after 6.1 yr			
No. 2	17.6	15.9	4.8	64	60	20.8	20.5	22.6	2.8
No. 12	17.9	16.5	4.9	34	30	100 Perforations, ⅛ in.			
No. 16	16.6	14.3	4.3	34	32	10 Perforations, 1/16 in.			
No. 3	16.6	14.2	4.3	57	55	18.3	23.0	20.6	2.9
GROUP IV—HIGH MANGANESE AND SILICON PLUS COPPER									
No. 18	16.2	16.0	4.8	33	31	200 Perforations, ⅛ in.			
No. 19	17.2	14.3	4.3	35	33	50 Perforations, ⅛ in.			
No. 17	16.3	13.1	3.9	29	28	60 Perforations, 1/16 in.			
No. 66	17.4	13.9	4.2	77	75	17.5	22.8	20.1	2.9
No. 53	16.1	12.4	3.7	55	54	17.5	21.0	19.3	3.1
GROUP V—COPPER STEEL PLUS CHROMIUM AND SILICON									
No. 67	12.6	7.54	2.3	62	61	12.8	11.8	12.3	3.2
No. 68	12.7	7.62	2.3	62	60	13.8	15.0	14.4	3.7
No. 154	12.4	6.40	1.9	50	49	11.5	12.0	11.8	3.6
No. 97	14.7	7.77	2.3	38	38	14.8	15.3	15.0	3.8
No. 13	16.3	6.54	2.0	35	34	12.5	16.0	14.3	4.3
GROUP VI—COPPER STEEL PLUS MOLYBDENUM									
No. 118	20.7	21.8	6.5	76	70	21.5	37.0	32.3	2.9
No. 120	19.6	21.1	6.3	77	71	25.0	39.0	35.0	3.3
No. 38	16.4	12.1	3.6	60	59	17.8	21.8	19.8	3.2
No. 121	17.4	14.0	4.2	74	72	18.8	23.0	20.9	3.0
No. 48	16.9	10.9	3.3	73	71	13.8	18.0	15.9	2.9
GROUP VII—NICKEL STEELS									
No. 32				32		Missing after 8.3 yr			
No. 27	15.7	14.9	4.5	27	25	500 Perforations, ⅛ in.			
No. 33				32		Disintegrating at 7.2 yr			
No. 34	16.4	12.8	3.8	33	32	50 Perforations, ⅛ in.			
No. 28	15.6	10.6	3.2	27	26	30 Perforations, 1/16 in.			
No. 147	16.1	9.54	2.9	30	30	4 Perforations, tiny		15.0	3.1
No. 46	15.0	8.30	2.5	29	28	11.8	14.5	13.1	3.1
No. 35	14.7	10.2	3.1	32	31	11.8	15.5	13.6	2.6
No. 20	16.1	8.05	2.4	29	28	14.3	12.3	13.3	3.3
No. 62	21.7	[b]	[b]	47	46	14.0	14.5	14.3	[b]
No. 36	15.3	7.10	2.1	35	35	10.3	11.3	10.8	3.0

TABLE I.—*Continued*

Material	Total Rust on Specimens, g	Weight Loss		Thickness, mil		Pitting mil, Average of 4 Deepest		Average Pit Depth, mil[a]	Pitting Factor
		g per sq dm	Mdd	At Start	Max at End	Top	Bottom		
GROUP VIII—NICKEL STEEL PLUS CHROMIUM									
No. 30	24.9	[b]	[b]	29	28	60 Perforations, ⅛ in.			
GROUP IX—NICKEL STEEL PLUS MOLYBDENUM									
No. 29	15.7	7.56	2.3	29	29	17.3	17.3	17.3	4.5
GROUP X—NICKEL STEEL PLUS CHROMIUM AND MOLYBDENUM									
No. 51	16.3	5.36	1.6	37	36	11.5	15.3	13.4	4.9
No. 52	15.8	5.56	1.7	34	34	14.0	14.0	14.0	5.0
GROUP XI—NICKEL-COPPER STEELS									
No. 37	14.9	9.10	2.7	63	63	14.0	16.0	15.0	3.3
No. 60	15.1	10.10	3.0	42	41	15.3	16.8	16.0	3.1
No. 148				28		Missing after 7.2 yr			
No. 50	13.3	6.30	1.9	28	28	10.5	12.5	11.5	3.6
No. 39	15.2	9.50	2.9	66	65	13.3	15.8	14.5	3.0
No. 149	15.4	7.58	2.3	31	30	15.0	16.3	15.6	4.1
No. 150	15.9	7.98	2.4	32	31	14.0	14.0	14.0	3.5
No. 153	14.8	6.64	2.0	28	27	12.3	11.0	11.6	3.5
No. 152	13.9	6.39	1.9	32	31	11.3	12.8	12.0	3.7
No. 151	13.7	6.38	1.9	31	31	12.8	13.0	12.9	4.0
GROUP XII—NICKEL-COPPER STEEL PLUS CHROMIUM									
No. 49	17.2	13.1	3.9	74	72	15.8	19.8	17.8	2.7
No. 16-1	18.5	14.5	4.4	32	30	100 Perforations, ⅛ in.			
No. 59	18.4	9.05	2.7	65	63	17.0	19.3	18.1	4.0
No. 47	18.4	8.48	2.5	30	30	14.3	16.8	15.5	3.6
No. 14	16.9	8.61	2.6	49	49	14.8	19.3	17.0	3.9
GROUP XIII—NICKEL-COPPER STEEL PLUS MOLYBDENUM									
No. 119	17.3	17.0	5.1	79	75	22.5	29.8	28.1	3.3
No. 65	16.8	10.6	3.2	79	78	15.5	18.5	17.0	3.2

[a] Corrected for loss in maximum thickness, provided correction was greater than 1 mil.
[b] Attacked in cleaning.

unimportant on the better steels. At Bayonne edge effects continued unimportant.

WEIGHT LOSSES

Weight loss time curves are plotted in Figs. 1 through 4. All the plots are on the same scale and permit accurate comparisons between the curves. The weight losses are indicated both as grams per sq dm and as mils. Dubious points, where there may have been some attack in cleaning, have been omitted in the plots. In general, the smoothness of the curves attests to the high accuracy of the data.

A noticeable feature of the plots is that at Block Island the curves are comparatively straight for the poorer steels with high weight losses resulting. At Bayonne the flattening of the curves after the first year or so was more pronounced. At 9 yr the corrosion was much less severe in the industrial atmosphere than in the marine atmosphere.

The average corrosion rates of some of the better steels had decreased to some remarkably low values. Thus at

TABLE II.—9 YR RESULTS AT BAYONNE.

Exposed: 5-12-41. Removed: 6-23-50

Time: 3329 days or 9.12 yr

Area: 3.15 sq dm, except 2.37 sq dm for steels No. 67, 68, 154, and 2.63 sq dm for steel No. 97

Material	Total Rust on Specimens, g	Weight Loss		Thickness, mil		Pitting, mil Average of 4 Deepest		Average Pit Depth, mil[a]	Pitting Factor
		g per sq dm	mdd	At Start	Max at End	Top	Bottom		
GROUP I—HIGH PURITY IRON PLUS COPPER									
No. 44				77		Corroded away at 4 yr.			
No. 45	17.0	31.80	9.6	71	63	10 Perforations, 1/16 in.			2.2
No. 63	16.3	16.09	4.8	80	78	19.3	19.8	19.5	2.4
No. 54	15.0	13.48	4.1	49	49	16.5	20.5	18.5	2.7
No. 55	14.2	10.78	3.2	47	46	14.3	15.8	15.0	2.8
GROUP II—LOW PHOSPHORUS STEEL PLUS COPPER									
No. 10	15.4	17.69	5.3	50	48	22.5[c]	21.5[c]	22.0	2.5
No. 31	14.4	14.99	4.5	31	30	300 Perforations, 1/16 in.			
No. 5	14.6	15.80	4.8	29	28	600 Perforations, 1/8 in.			
No. 57	13.8	10.62	3.2	50	49	14.8	18.3	16.5	3.1
No. 6	13.9	10.43	3.1	31	30	10 Perforations, tiny			
No. 41	14.0	10.29	3.1	77	76	14.0	15.8	14.9	2.9
No. 43	14.8	10.54	3.2	80	79	14.0	15.3	14.6	2.8
No. 64	13.9	10.19	3.1	82	80	12.0	16.0	14.0	2.7
No. 40	13.8	10.19	3.1	64	63	14.5	15.8	15.1	2.9
No. 58	13.8	9.89	3.0	62	61	13.5	15.8	14.6	2.9
No. 42	13.4	8.89	2.7	76	75	14.5	15.0	14.8	3.3
No. 56	13.5	9.99	3.0	49	49	14.8	15.0	14.9	3.0
No. 7	13.2	9.37	2.8	27	26	40 Perforations, tiny			
GROUP III—HIGH PHOSPHORUS STEEL PLUS COPPER									
No. 1	14.8			57		Disintegrating			
No. 11	13.4	12.60	3.8	33	31	40 Perforations, tiny			
No. 2	12.6	8.74	2.6	64	63	13.0	15.0	14.0	3.2
No. 12	12.3	9.13	2.7	34	33	12.8	13.5	13.1	2.9
No. 16	11.8	8.29	2.5	35	34	10.5	11.8	11.1	2.7
No. 3	12.0	7.19	2.2	58	57	11.8	12.5	12.1	3.3
GROUP IV—HIGH MANGANESE AND SILICON PLUS COPPER									
No. 18	8.1	9.73	3.0	32	30	8 Perforations, tiny		16	3.3
No. 19	13.6	11.27	3.4	35	34	13.0	15.5	14.3	2.5
No. 17	12.4	8.27	2.6	29	28	13.0[c]	12.5[c]	12.8	3.1
No. 66	14.6	10.11	3.0	78	76	12.8	15.5	14.1	2.8
No. 53	11.7	7.89	2.4	56	55	11.3	12.5	11.9	3.0
GROUP V—COPPER STEEL PLUS CHROMIUM AND SILICON									
No. 67	8.7	7.93	2.4	62	61	13.0	14.3	13.6	3.4
No. 68	8.5	6.82	2.1	48	46	11.3	11.5	11.4	3.3
No. 154	7.6	4.30	1.3	49	47	9.5	9.3	9.4	4.3
No. 97	9.7	5.93	1.8	38	37	12.8	12.8	12.8	4.3
No. 13	10.3	3.48	1.1	35	34	10.3	10.5	10.4	5.9
GROUP VI—COPPER STEEL PLUS MOLYBDENUM									
No. 118	13.7	9.44	2.8	75	74	13.0	14.3	13.6	2.9
No. 120	13.3	8.76	2.6	77	76	14.3	15.0	14.6	3.3
No. 38	11.9	8.24	2.5	60	60	12.0	13.3	12.6	3.0
No. 121	12.3	7.08	2.1	74	73	11.3	12.0	11.6	3.3
No. 48	11.5	6.53	2.0	71	70	10.0	12.5	11.3	3.4
GROUP VII—NICKEL STEEL									
No. 32	13.1	12.19	3.7	31	31	25 Perforations, 1/16 in.		15.5	
No. 27	13.5	9.70	2.9	28	27	12.8	15.5	14.1	2.9
No. 33	13.4	10.89	3.3	33	31	14.8[c]	15.8[c]	15.3	2.8
No. 34	11.6	8.10	2.4	33	31	12.8	13.3	13.0	3.2
No. 28	11.1	7.89	2.4	29	28	10.8	10.0	10.4	2.6
No. 147	10.4	7.15	2.2	30	30	9.3	11.8	10.5	2.9
No. 46	11.8	6.96	2.1	28	28	9.5	10.8	10.1	2.9
No. 35	12.9	[b]	[b]	32	31	10.5	12.5	11.5	[b]
No. 20	10.5	6.27	1.9	29	29	9.0	9.0	9.0	2.9
No. 62	10.0	4.91	1.5	46	45	7.3	7.3	7.3	2.9
No. 36	9.7	5.57	1.7	34	34	9.0	7.3	8.1	2.9

TABLE II.—*Continued*

Material	Total Rust on Specimens, g	Weight Loss		Thickness, mil		Pitting, mil. Average of 4 Deepest		Average Pit Depth, mil[a]	Pitting Factor
		g per sq dm	mdd	At Start	Max at End	Top	Bottom		
GROUP VIII—NICKEL STEEL PLUS CHROMIUM									
No. 30	11.3	6.44	1.9	30	29	11.5	11.3	11.4	3.5
GROUP IX—NICKEL STEEL PLUS MOLYBDENUM									
No. 29	10.3	6.17	1.9	30	29	10.8	10.5	10.6	3.4
GROUP X—NICKEL STEEL PLUS CHROMIUM AND MOLYBDENUM									
No. 51	10.2	3.78	1.1	38	37	10.8	10.5	10.6	5.6
No. 52	9.9	4.57	1.4	34	33	9.5	9.8	9.6	4.2
GROUP XI—NICKEL-COPPER STEELS									
No. 37	10.2	5.47	1.6	64	64	10.0	10.5	10.3	3.7
No. 60	11.2	6.74	2.0	42	40	10.5	11.0	10.8	3.1
No. 148	10.8	5.39	1.6	31	30	10.5	11.5	11.0	4.0
No. 50	12.1	4.80	1.4	28	28	11.5	9.3	10.4	4.3
No. 39	10.7	6.37	1.9	66	66	10.8	10.8	10.8	3.3
No. 149	10.4	5.32	1.6	31	31	9.8	10.0	9.9	3.7
No. 150	10.8	5.02	1.5	32	31	10.0	9.3	9.6	3.8
No. 153	13.6	*b*	*b*	30	29	10.3	9.8	10.0	*b*
No. 152	14.8	*b*	*b*	32	31	8.8	8.5	8.6	*b*
No. 151	15.5	*b*	*b*	32	31	12.3	9.5	10.9	*b*
GROUP XII—NICKEL-COPPER STEEL PLUS CHROMIUM									
No. 49	11.9	7.63	2.3	74	74	10.5	12.8	11.6	3.0
No. 16-1	11.9	7.33	2.2	31	31	11.0	13.5	12.3	3.3
No. 59	11.8	5.89	1.8	65	65	10.3	12.3	11.3	3.8
No. 47	11.9	5.79	1.7	31	31	11.0	12.3	11.6	4.0
No. 14	10.6	5.41	1.6	53	52	13.0	11.5	12.3	4.5
GROUP XIII—NICKEL-COPPER STEEL PLUS MOLYBDENUM									
No. 119	12.4	7.96	2.4	79	79	12.0	15.0	13.5	3.4
No. 65	10.7	6.24	1.9	79	79	10.8	10.8	10.8	3.4

[a] Corrected for loss in maximum thickness, provided correction was greater than one mil.
[b] Attacked in cleaning.
[c] Two tiny perforations.

Bayonne the corrosion rates from the fifth to the ninth year were below 1 mdd (milligram per sq dm per day) for about twenty of the steels. In Fig. 4(*a*) and in Fig. 13(*b*) the corrosion rate of steel No. 20 was exactly 1 mdd for this period. At Block Island the corrosion rates were higher, but some of the better steels still averaged near 1 mdd.

In the figures the curves are arranged in groups. There was very little crossing of the curves within the groups and most of this was probably within experimental error. Comparison of the groups, however, shows some relative changes in slope. These were adequately discussed previously (2) and can be accounted for on the basis of composition. Chromium was particularly effective in flattening weight loss-time curves. In general, copper and chromium were more helpful at Bayonne, and manganese was more helpful at Block Island. Compositional effects are further discussed below.

For the most part, the curves continued to diverge with time. Differences between the steels were more noticeable at 9 yr than at shorter periods. In other words, the benefit of alloying increased with time.

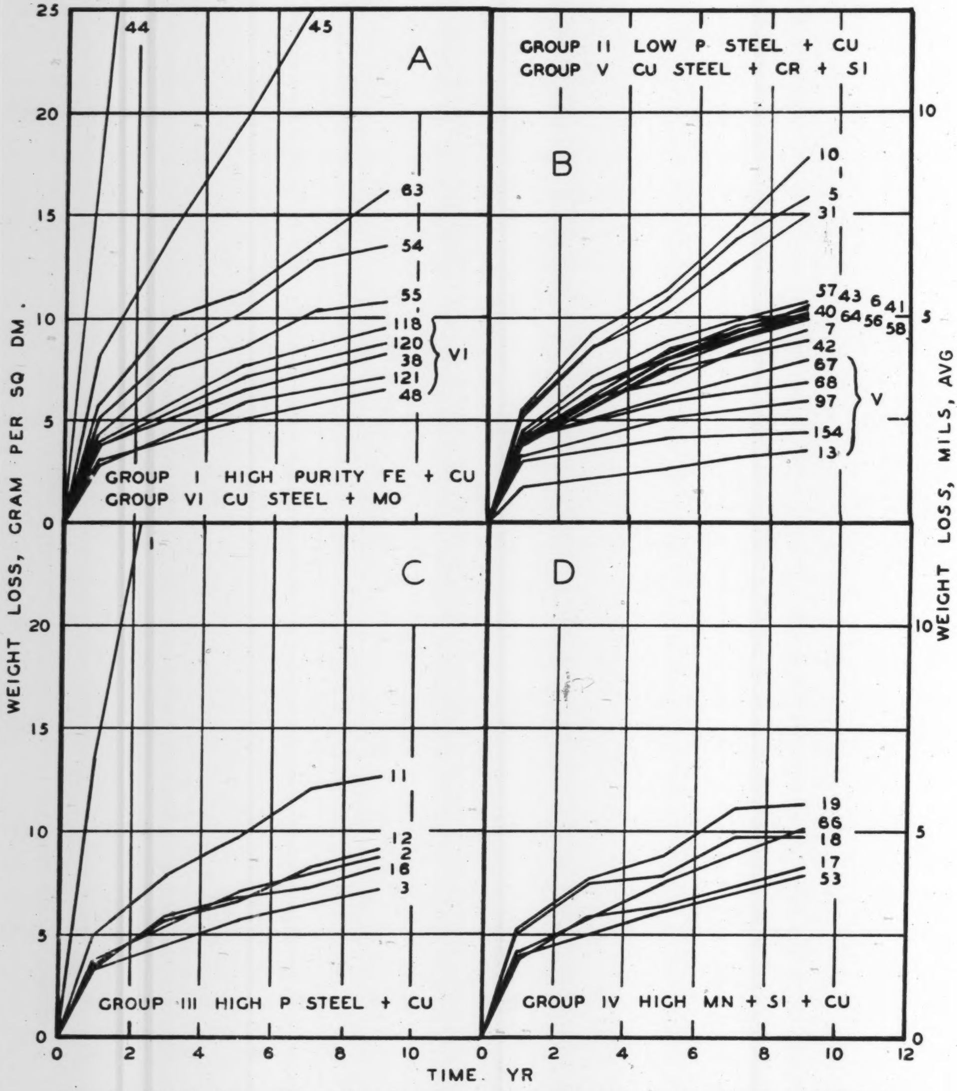

Fig. 3.—Weight Loss—Time Curves at Bayonne for Steels Substantially Free of Nickel.

Pit Depths

Pit depth-time curves are plotted in Figs. 5 through 8. These plots are on the same scale. As was to be expected, there is more scatter in these curves than in the weight loss curves. Also, the curves are not as complete because badly perforated specimens could not be included. Nevertheless the general trends are quite evident.

At Bayonne, pits were scarcely any deeper at 7 and 9 yr than at 5 yr. On many of the steels, pit depths had leveled off between 10 and 12 mils. At Block Island, on the other hand, the pitting rate after the first year was more nearly constant and on the surviving steels was about 1 to 3 mils per year, all the pits being deeper than at Bayonne.

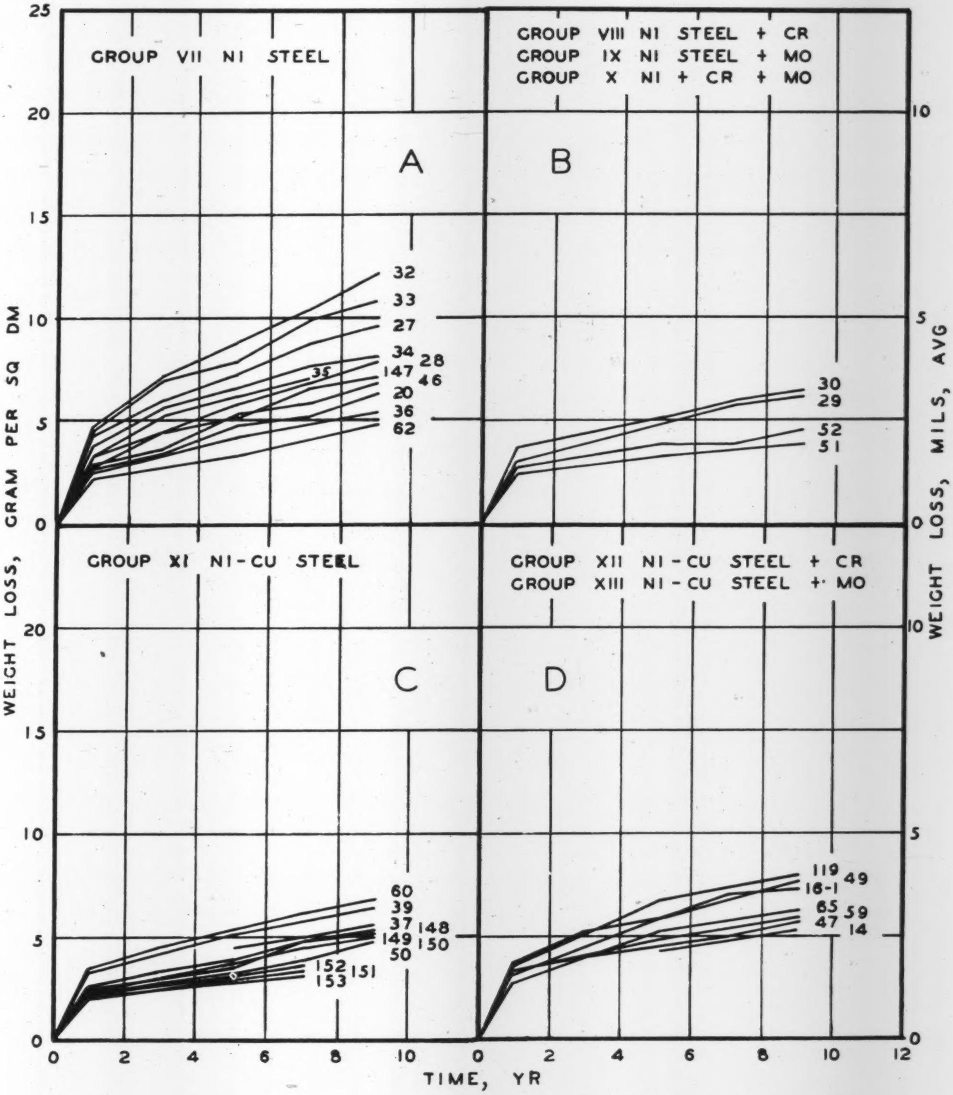

FIG. 4.—Weight Loss—Time Curves at Bayonne for Steels Containing Nickel.

Presumably new pits were forming and old ones widening at both locations, but at Bayonne after 5 yr practically all the increased weight loss was due to these factors rather than to deepening of the old pits. In spite of this, much of the original surface was still present except on the more severely corroded steels.

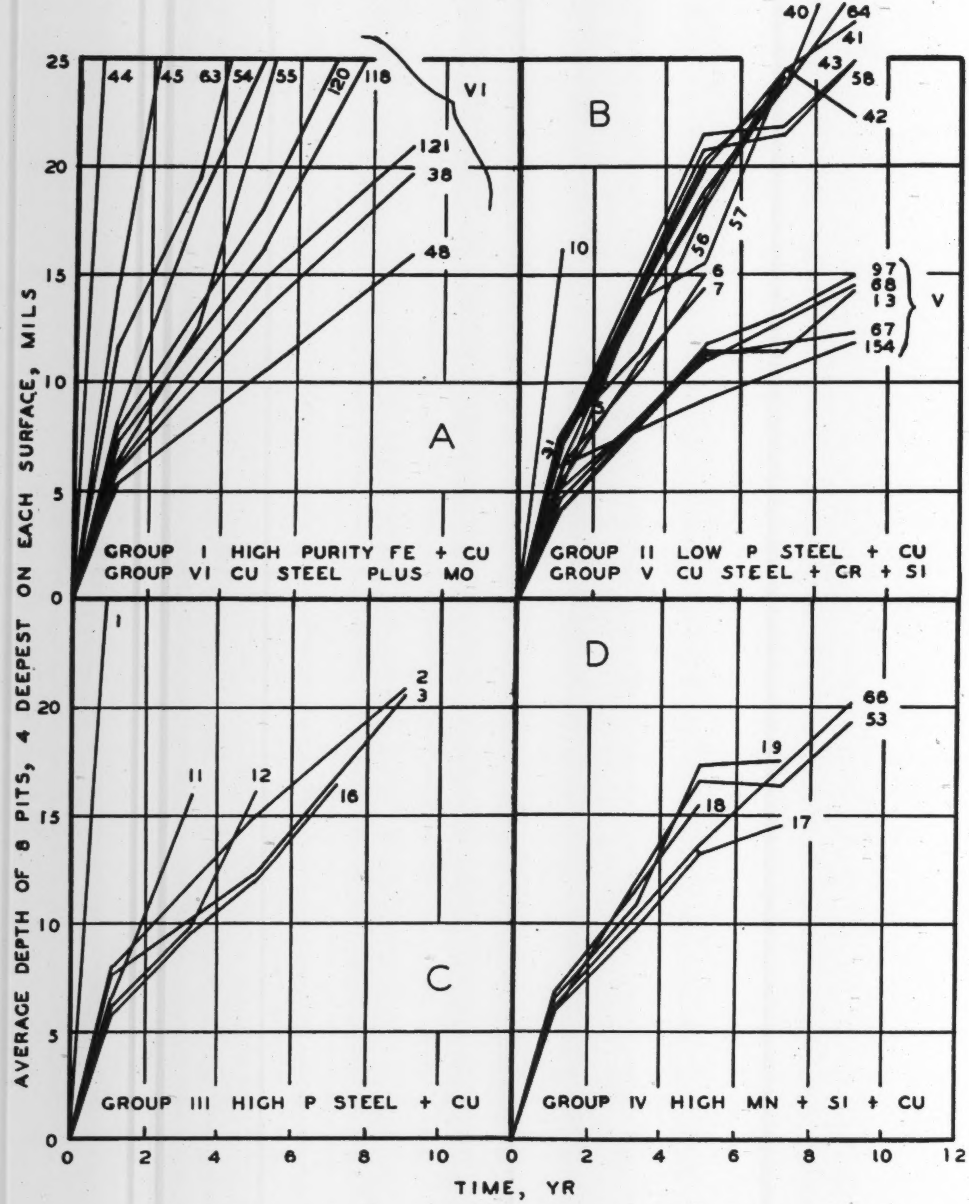

FIG. 5.—Pit Depth—Time Curves at Block Island for Steels Substantially Free of Nickel.

An important observation is that the pit depths do not rate the steels in exactly the same order as the weight losses. This was largely a matter of group behavior, with steels containing chromium tending to have fewer but relatively deep pits, and steels containing nickel tending to have more but shallower pits. This point was emphasized in Fig. 9 of the 1948 paper (2) and was equally true at 9 yr.

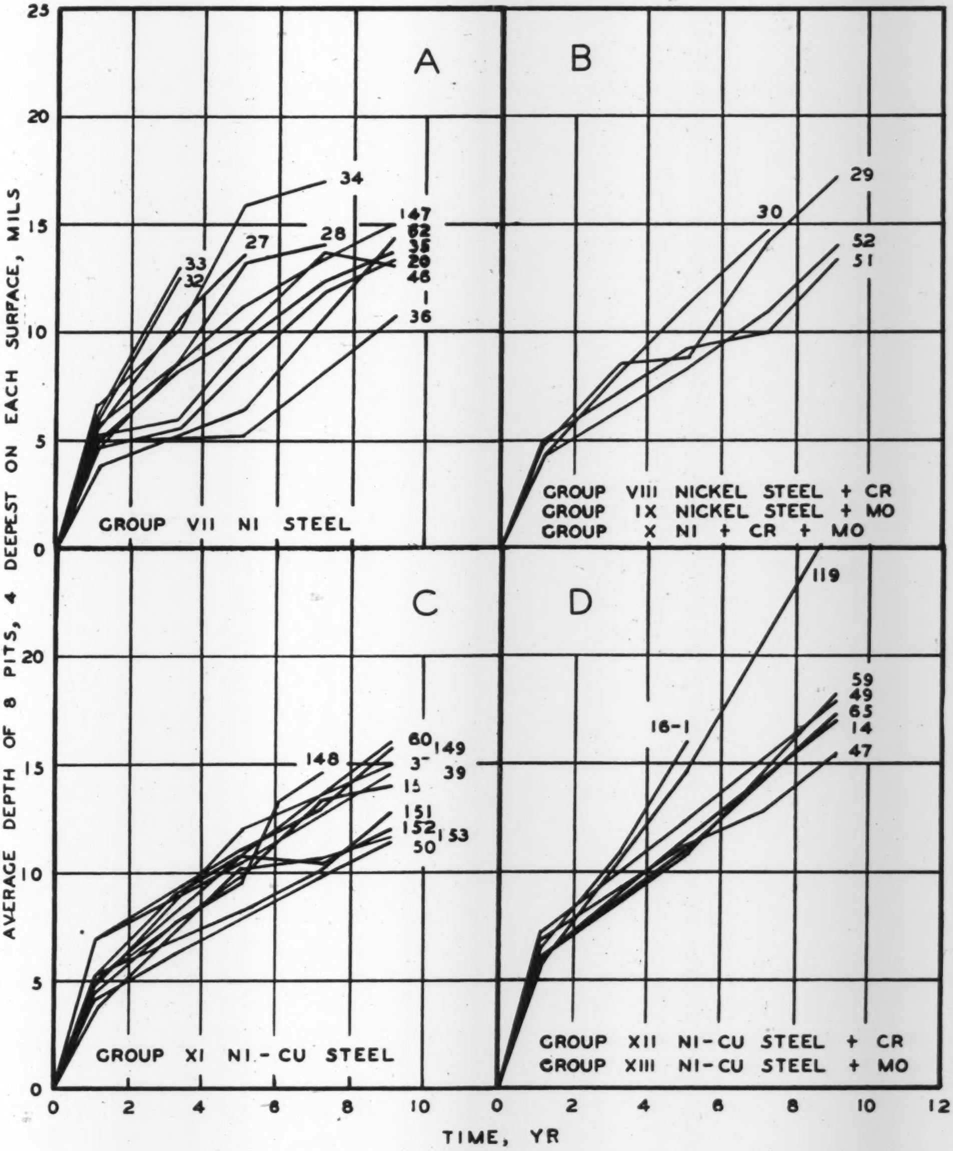

FIG. 6.—Pit Depth—Time Curves at Block Island for Steels Containing Nickel.

Some differences in group behavior are brought out in Table III. Results for the steels of Groups II, V, VII, XI, and XII, which were in good condition at 9 yr at both Block Island and Bayonne, have been averaged. At 1 yr the four nickel steels of Group VII, which met the above qualification, had the lowest average weight loss. By 9 yr at

Bayonne the copper-chromium-silicon steels of Group V, the nickel-copper steels of Group XI, and the nickel-copper-chromium steels of Group XII had all surpassed these nickel steels as far as low weight loss was concerned. However, at 9 yr the nickel steels had the shallowest pit depths. Similarly, at Block Island at 9 yr Group V had passed Group VII with regard to weight losses, but the nickel steels again had the lowest pit depths.

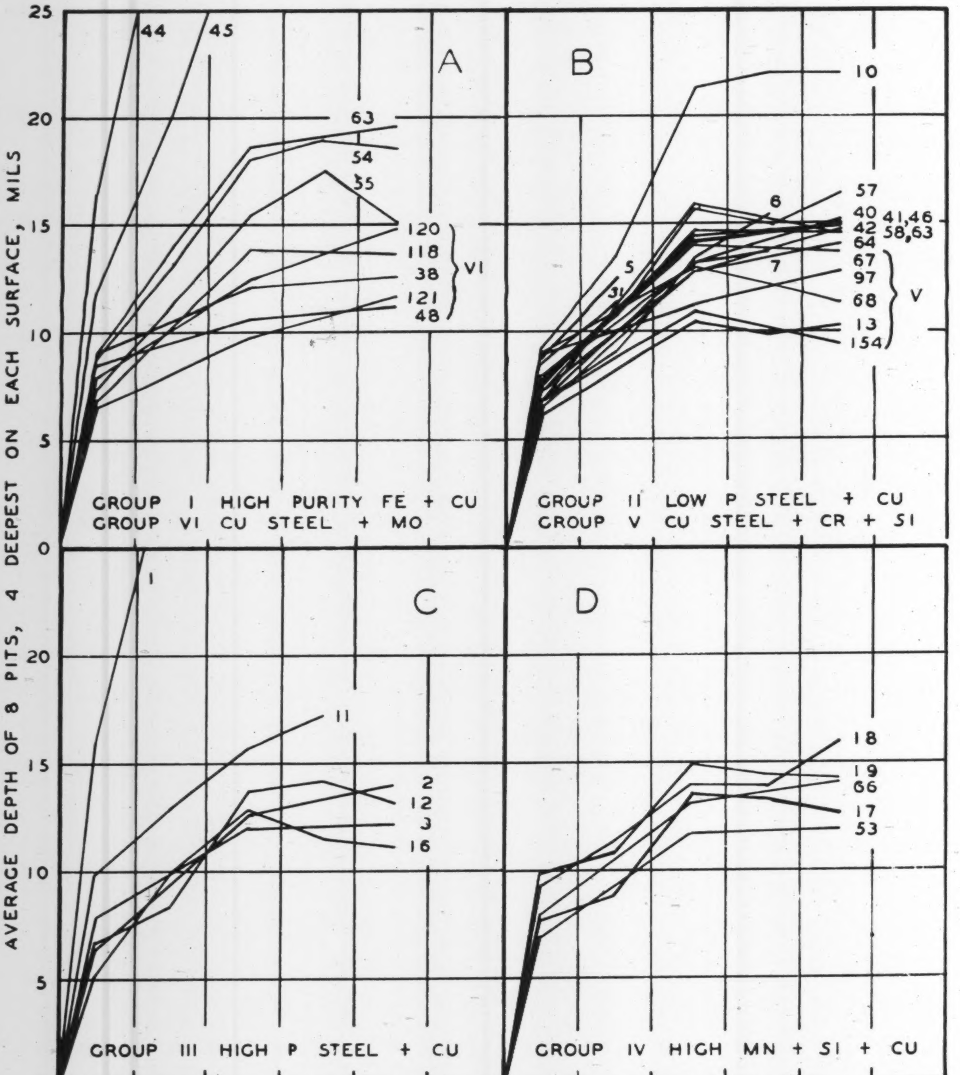

Fig. 7.—Pit Depth—Time Curves at Bayonne for Steels Substantially Free of Nickel.

The averages in Table III confirm that chromium was particularly effective in flattening weight loss time curves and that copper and chromium were more effective at Bayonne than at Block Island. Nickel additions to steel produced a low initial weight loss, and on long exposure nickel was particuarly effective in decreasing pit depths.

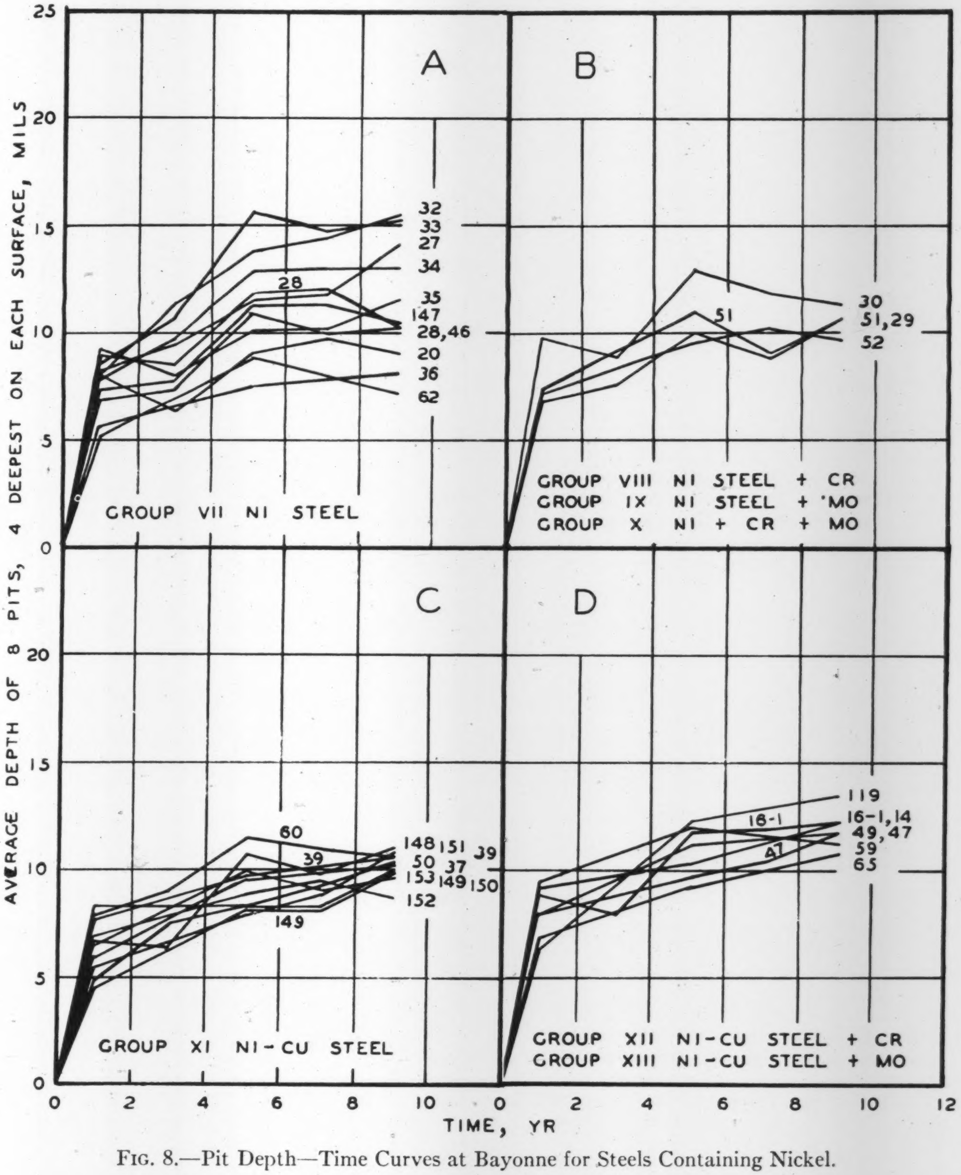

FIG. 8.—Pit Depth—Time Curves at Bayonne for Steels Containing Nickel.

As can be seen in Table III, the beneficial effect of alloying was not as marked in decreasing pit depths as in decreasing weight losses. For example, at 1 yr at Bayonne the complex alloyed chromium steels of Groups V and XII had deeper pits but lower weight losses than the copper steels of Group II. In general, alloying decreased both the pit depths and the number of pits, particularly on long exposure.

TABLE III.—COMPARISON OF GROUP BEHAVIOR.

Group	Steels Averaged			1 Yr			5 Yr			9 Yr		
				Average Weight Loss, mil	Average Pit Depth, mil	Average Pitting Factor	Average Weight Loss, mil	Average Pit Depth, mil	Average Pitting Factor	Average Weight Loss, mil	Average Pit Depth, mil	Average Pitting Factor
						BAYONNE, N J.						
II	41 43	64 40	58 42	2.0	7.3	3.6	4.0	14.0	3.5	5.0	14.7	2.9
V	67 68	154 97	13	1.6	8.1	4.9	2.4	12.8	5.3	2.9	12.2	4.2
VII	147 46	20 36		1.3	6.6	5.2	2.5	9.6	3.9	3.3	9.5	2.9
XI	37 60	50 39	149 150	1.4	6.4	4.5	2.1	9.7	4.6	2.8	10.3	3.7
XII	49 59	47 14		1.7	8.7	5.3	2.5	10.9	4.4	3.1	11.8	3.8
						BLOCK ISLAND, R. I.						
II	41 43	64 40	58 42	1.9	7.2	3.8	7.2	20.2	2.8	11.4	28.8	2.5
V	67 68	154 97	13	1.2	5.1	4.1	2.6	10.7	4.0	3.6	13.4	3.7
VII	147 46	20 36		1.1	5.1	4.6	2.7	8.6	3.2	4.2	13.0	3.1
XI	37 60	50 39	149 150	1.2	5.7	4.7	3.0	10.4	3.5	4.3	14.6	3.4
XII	49 59	47 14		1.3	6.6	5.0	3.3	11.6	3.6	4.9	17.5	3.6

NOTE.—Minimum loss in thickness was 0.5 mil, except for Group II at Block Island.

As recorded in Tables I and II, pit depths tended to be deeper on the groundward surface. The effect was pronounced on the faster corroding steels, and nonexistent for some of the better steels. Weight losses have been considered to be greater on the groundward surface (3), but there may be some variation in this with respect to different steels. Additional effects of shelter were discussed previously (2).

PITTING FACTORS

The pitting factors in Tables I and II are the ratio of the depth of the deepest pits, the four deepest on each surface, to the average depth of corrosion as shown by weight losses. The pitting factors ranged from 2.2 to 5.9, meaning that pits had penetrated 2 to 6 times deeper than the average attack shown by weight losses.

In general, the pitting factors for a given steel tended to decrease with time. This was an accelerating process at Bayonne, but a decelerating one at Block Island. For a given weight loss, pitting factors initially were smaller at Block Island, but with time this has reversed.

Pitting factors are an effective means

of showing the relative behavior of different steels. Pitting factors were smaller on the fast corroding steels and larger on the better steels. Steels containing chromium had comparatively large pitting factors, and steels containing nickel had comparatively small pitting factors.

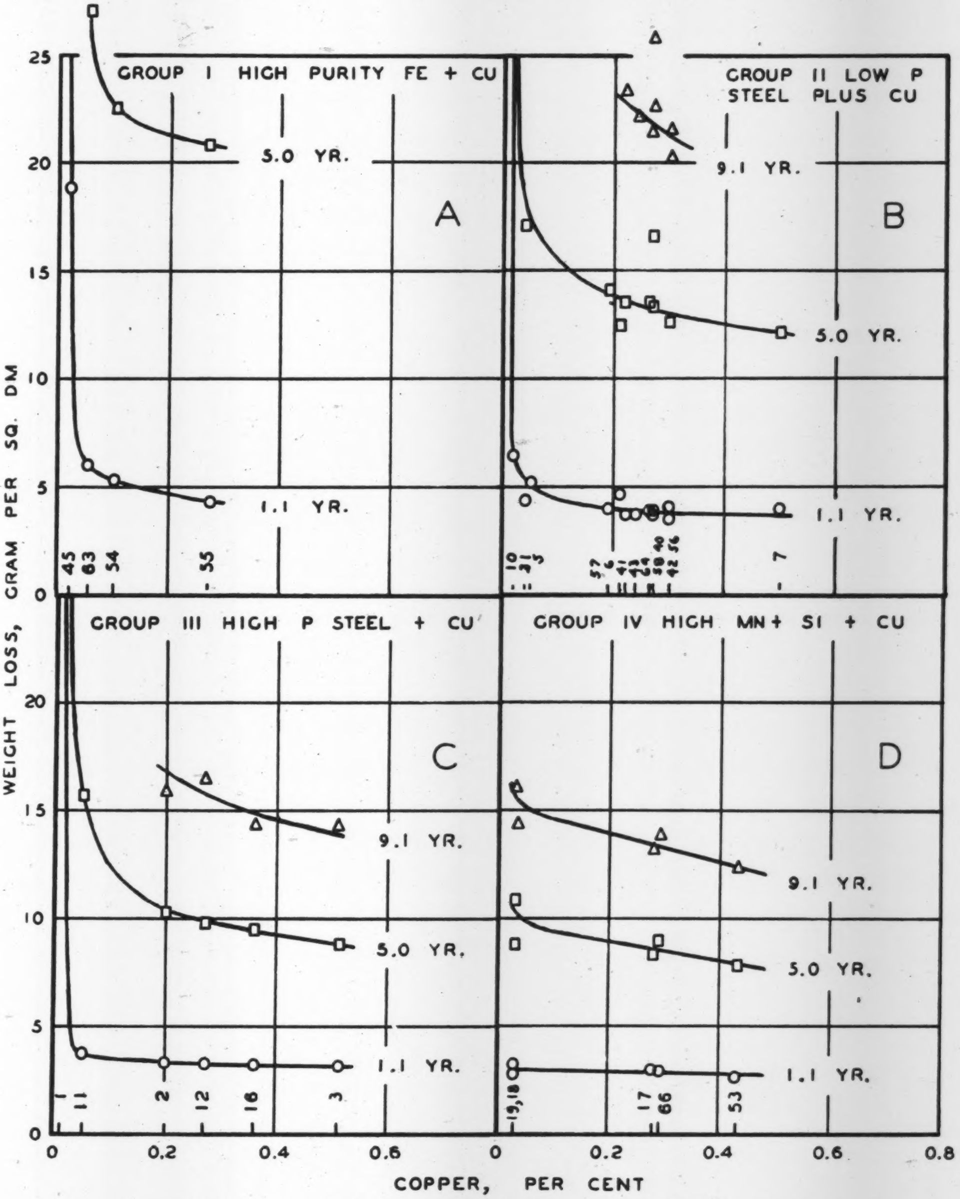

FIG. 9.—Weight Loss *versus* Copper Content of Groups I, II, III, IV at Block Island.

The pitting factors give an indication of the percentage of the area of the specimen suffering corrosion. On the

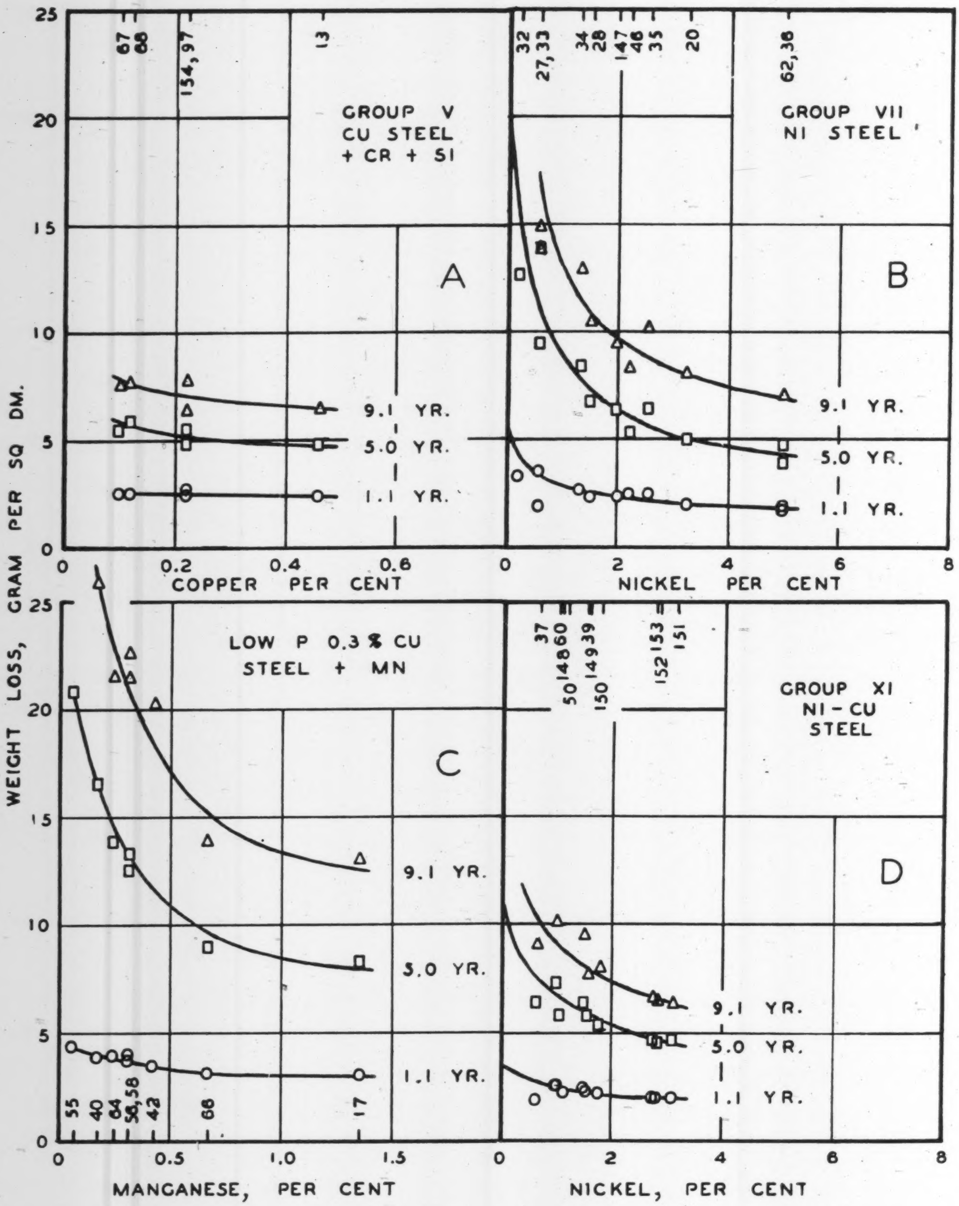

FIG. 10.—Weight Loss *versus* Copper Manganese or Nickel Content of Certain Steels at Block Island.

assumptions that the pits had vertical walls, that they were of uniform depth, and that there was no attack elsewhere, the reciprocal of the pitting factor multiplied by 100 gives the percentage of the area pitted. At Bayonne on nickel steel No. 62 this gives 34 per cent of the total area pitted to a depth of 7.3 mils and an average depth of attack 2.5 mils. On steel No. 13 of Group V it gives 17 per cent of the total area pitted to a depth of 10.4 mils and an average depth of attack 1.8 mils. The assumptions, of course, are not precise and actually the percentage of the total area pitted should be about doubled. Photographs showing the nature of the attack on chromium steels were published by Binder and Brown (4).

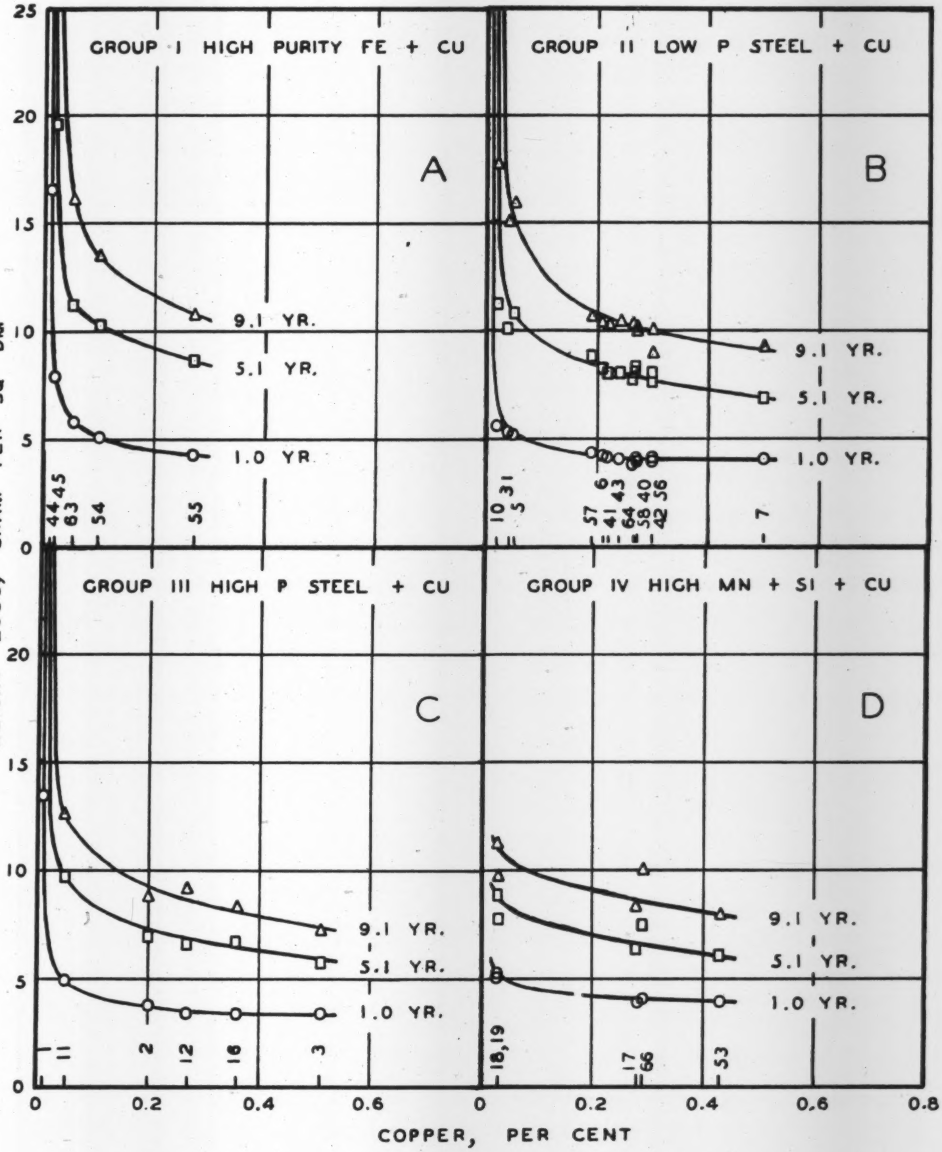

Fig. 11.—Weight Loss *versus* Copper Content of Groups I, II, III, IV at Bayonne.

It should be emphasized that the pitting factors apply only to the conditions of exposure actually used. They might increase with the severity of conditions until the entire surface was attacked and then decrease again. Comparatively deep pits have been reported in crevices (5).

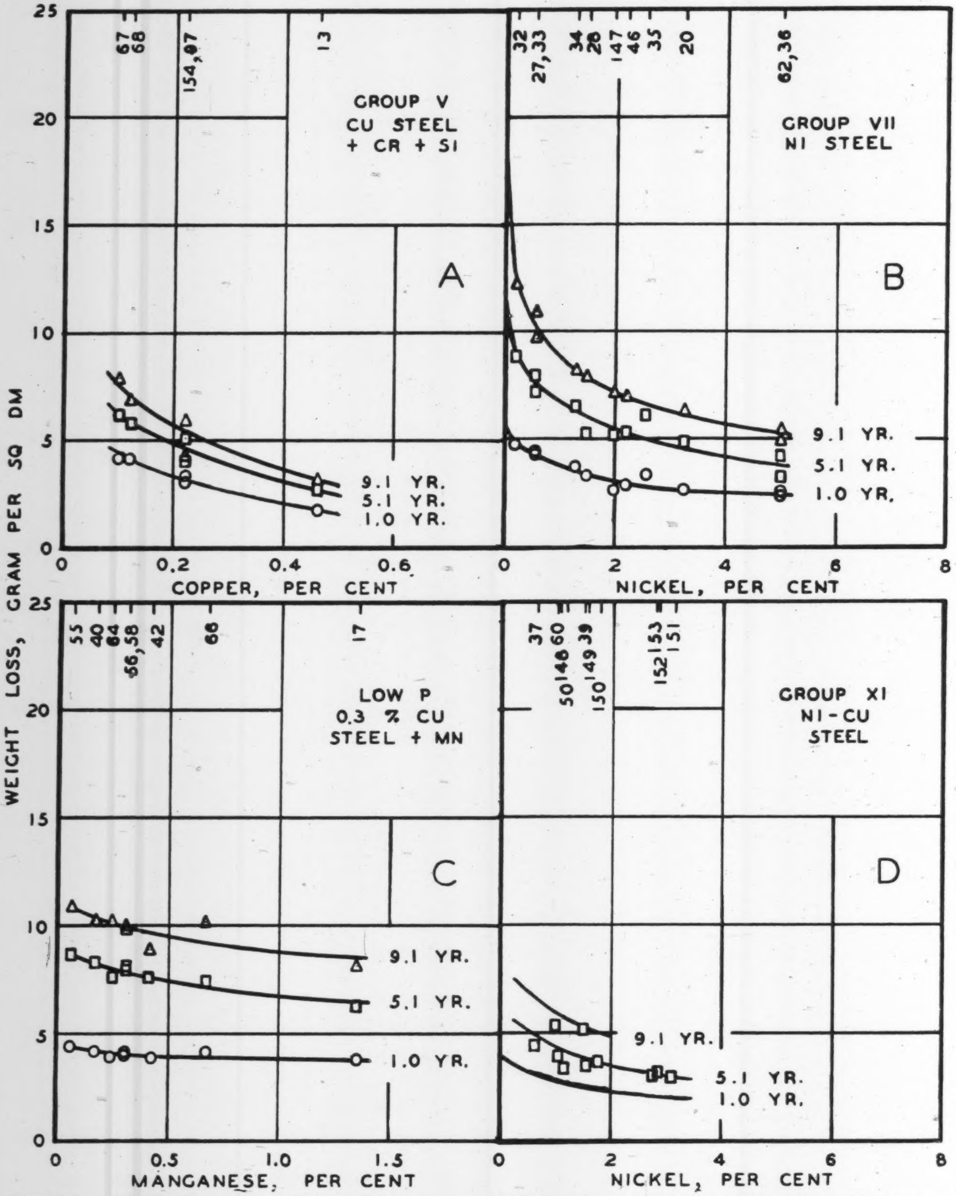

FIG. 12.—Weight Loss *versus* Copper Manganese or Nickel Content of Certain Steels at Bayonne.

EFFECTS OF COMPOSITION

Weight loss composition curves are plotted in Figs. 9 through 12. The weight loss scale is the same as in the other plots. Results are plotted for 1, 5, and 9 yr, and the points for all the steels are identified, except for some of the very high weight losses which are off the plots and for Group XI at Bayonne where the points would superimpose. The curves are consistent with each other. The intercepts for the nickel steels of Group VII were read from the Group II plots at 0.03 per cent copper. The intercepts for the nickel-copper steels of Group XI were read from the Group II plots at 1 per cent copper. In general, the curves are quite smooth.

The following discussion pertains particularly to weight losses, but the modifications due to pit depths should be kept in mind. Accurate pit depth composition curves could not be drawn owing to the scatter in these results. Previous conclusions with regard to composition (2) were well supported by the new data.

Copper:

Unalloyed very low copper steels corroded at exceedingly high rates. The highest weight losses were far off the graphs. The first few hundredths per cent copper had a big effect in lowering the weight losses. More copper was considerably less effective. At one year there was little merit in more than 0.1 per cent copper in the plain steels at either Block Island or Bayonne. The shape of the curves changed with time, however, and in the older tests there was continued improvement with copper up to 0.5 per cent or higher.

In the more highly alloyed steels, copper additions were more effective at the industrial location. Thus, in the Group V steels, Fig. 10(*a*) and Fig. 12(*a*), fractional percentages of copper lowered the weight losses at Bayonne but had little effect at Block Island. In the Group XI steels replacing 1 per cent of nickel with 1 per cent of copper produced a bigger decrease in weight at Bayonne than at Block Island.

Phosphorus:

Adding a little phosphorus to the copper steels was moderately helpful as shown by a comparison between Groups II and III. Phosphorus also seemed to be moderately helpful in many of the more complex steels.

Manganese:

Ingot irons containing copper, Group I, corroded at comparatively fast rates. The steels of Group II behaved better, due at least in part to their higher manganese content. The improvement was particularly pronounced at Block Island. The Group IV steels did quite well, particularly at Block Island, presumably due to their manganese content.

The effect of manganese in 0.3 per cent copper steels is shown in Fig. 10(*c*) and Fig. 12(*c*). Manganese was decidedly helpful at Block Island, but only slightly so at Bayonne. The beneficial effect was less pronounced at 1 yr than in the older results.

Nickel:

The effect of nickel is shown in Fig. 10(*b*) and Fig. 12(*b*). There was progressive improvement with increasing nickel although the law of diminishing returns applied. With time, the curves grew steeper and the improvement more noticeable. The high-nickel steels produced quite low weight losses. When the nickel content becomes much higher, for example around 35 per cent, flaking away of the protective rust may change the picture. At this nickel level, pitting may be so insignificant that the rust loses its mechanical adherence.

Other Elements:

The data do not permit a clear evaluation of the effect of other elements individually. Chromium is known to be effective in lowering weight losses (4). Molybdenum did not seem particularly valuable in Groups VI, IX, or XIII. Silicon generally seemed without much effect, although it probably was useful in the Group V steels. Carbon was generally low and no influence of this element was detected. Sulfur likewise was low, but this element is known to be harmful. The literature on the effect of composition on atmospheric corrosion was reviewed by French and LaQue (6).

Complex Steels:

In general, the combined influence of many elements together seemed beneficial, particularly on long exposure. The steels of Group V contained copper, chromium, silicon, and phosphorus and had quite low weight losses. Likewise the nickel-chromium-molybdenum steels of Group X had low weight losses. On the other hand, the addition of chromium or molybdenum separately to the nickel steels or to the nickel-copper steels was without marked benefit. It would be concluded that any new complex low alloy steel would have to be tested outdoors to evaluate truly its resistance to corrosion.

WEATHER CONTROLS

The purpose of some supplementary tests was to provide a means of observing any large change in the corrosiveness of the atmospheres. Specimens of steels No. 20 and No. 45 and of zinc (material No. 117) were exposed periodically as the other specimens were removed. Multiple specimens were exposed in 1941, 1942, 1944, 1946, and 1948, and identical sets were removed in 1942, 1944, 1946, 1948, and 1950. All the weight losses obtained are plotted in Fig. 13.

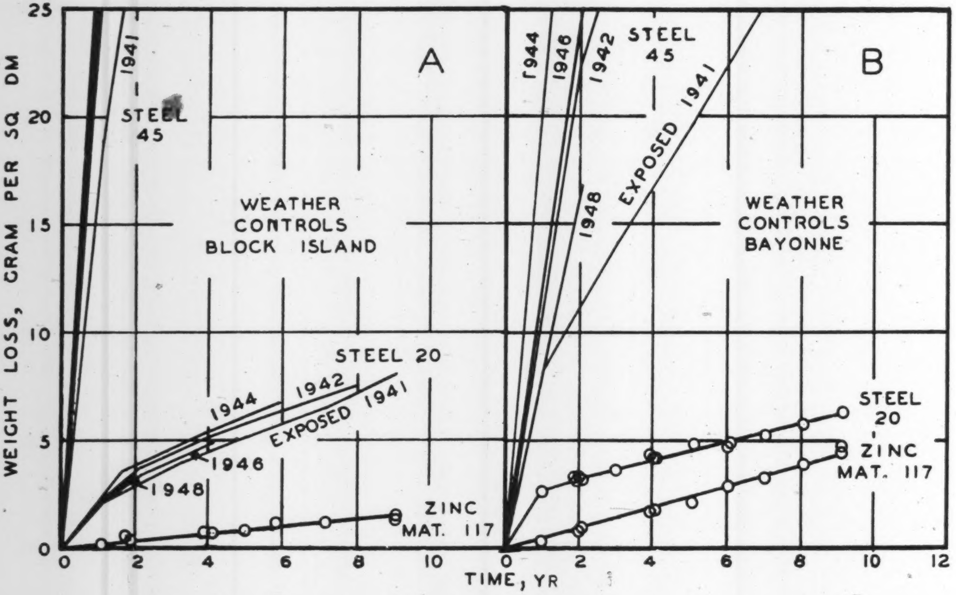

FIG. 13.—Weather Controls.

In the case of zinc, the year of exposure made little difference, all the points falling close to a straight line passing through the origin at both Bayonne and Block Island. If zinc always behaved this way, it would be a poor material to indicate variations in the weather. It seems established, however, that sometimes the corrosion rate of zinc can be profoundly influenced by the weather during the first few days of exposure and that the magnitude of this effect can be greater for zinc than for steel (7). Zinc is regarded as an unsatisfactory material for measuring the corrosivity of an atmosphere toward steel. Zinc corroded faster in the industrial atmosphere, and surprisingly its corrosion rate of 1.3 mdd was after the first year or two higher than the average corrosion rate of some of the better steels. Zinc corroded very uniformly.

In the case of steel, the year of exposure did have some influence on the weight loss. The magnitude of the effect varied with the resistance of the steel to attack. It is concluded that variations in the weather had little effect on the behavior of the more corrosion resistant steels (steel No. 20, Fig. 13(*b*)) but did have appreciable effect on the rate of attack of the poorer steels. If the attack was very fast, any influence of the weather was obscured (steel No. 45, Fig. 13(*a*)).

A study of the curves in Fig. 13 shows that conditions in the early stages of the tests had a lasting influence. The year 1941 was comparatively mild as far as the corrosion of steel was concerned, but conditions became progressively worse through 1942, 1944, and perhaps until 1946. Conditions then improved somewhat in the later years. In the earlier publications (1, 2), an attempt was made to correlate this behavior with weather data at Block Island. At Block Island two important factors seemed to be the percentage of days with light fog and the amount of wind from northerly directions when rain was falling. These factors probably reflected the humidity and pollution present.

As far as the present tests are concerned, it is concluded that variations in the atmospheric conditions from 1941 to 1950 were small enough so that they had no significant effect on the results. The shape of weight loss-time curves was not distorted. The largest effect was on the poorer steels which were comparatively widely separated. As far as any other tests on steels are concerned, it is concluded that control specimens should be included to facilitate comparisons between tests started at different times. Experience has shown this to be important in some cases.

CONCLUSIONS

1. Even after 9 yr the lowering of the surface level was only 1 mil or less for all the better steels. Most of the attack occurred in pits, and pit depths were important.

2. Pit depths did not rate the steels in the same order as weight losses. For example, steels containing chromium tended to have fewer but deeper pits, and steels containing nickel tended to have more but shallower pits.

3. Alloying decreased both pit depths and the number of pits, but the beneficial effect of alloying was more marked in decreasing weight losses than pit depths. Pitting factors ranged from 2 to 6 and were larger on the better steels.

4. The new data confirmed the beneficial effect of fractional percentages of copper, of small amounts of phosphorus, and of a per cent or more of nickel.

5. Nickel additions produced low initial weight losses, and on long exposure nickel was particularly effective in decreasing pit depths.

6. Chromium was particularly effective in flattening weight loss time curves. Chromium and copper additions to complex steels were more helpful at Bayonne, and manganese was more helpful at Block Island.

7. The flattening of the weight loss curves resulted in some remarkably low corrosion rates. From the fifth to the ninth year, rates below 1 mdd were fairly common.

8. The flattening of the weight loss curves was more pronounced at Bayonne.

At 9 yr, corrosion was much less severe at the industrial location.

9. Pit depths continued to deepen with time at Block Island, whereas at Bayonne pits were scarcely any deeper at 9 yr than at 5 yr.

10. All the time curves continued to diverge, meaning that the benefit of alloying increased with time.

11. Weather controls, which were exposed periodically, showed that variations in weather conditions from 1941 to 1950 had no significant effect on the results. Nevertheless, conditions near the start had a lasting influence. In tests started at different times, controls should be included to facilitate comparisons.

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A METHOD OF EVALUATING CORROSION BY MOLTEN METALS*

BY M. A. CORDOVI[1]

Selection of a suitable material to withstand certain corrosive environments or, conversely, the determination of environments in which a given material can be used satisfactorily is a common engineering problem. Evaluation of materials by actual service is, of course, ideal but usually is not practicable. The common practice, therefore, is to evaluate materials on the basis of short-time laboratory and plant tests conducted under natural or simulated exposure conditions. In view of the wide variance in the behavior of metals in different types of environments, there is some question whether or not the results of such tests can be properly interpreted in terms of actual service performance. Nevertheless, it is generally recognized that data on rates of corrosion which have been secured by accelerated laboratory tests serve as a valuable guide in engineering design and as a time saver in the solution of many industrial problems.

If short-time corrosion tests are to be used as criteria of field performance, they should be conducted under conditions which can be controlled within extremely close limits in order to simulate the conditions expected in service. The practical value of data derived from such tests depends largely on the accuracy to which the results are determined and on their reproducibility.

The extent of corrosion is usually determined by one or more of the following methods: visual inspection, loss in weight, gain in weight, depth of pitting, change in physical properties, microscopic examination, and others.[2] Some of these methods provide a means of measuring the amount of corrosion more or less quantitatively, while the others are useful only as qualitative aids. Thus, visual inspection is useful for determining whether or not any corrosion has occurred, and the microscope has been found to be a valuable auxiliary tool in studying the mode of attack, but obviously neither of these methods is suitable for a quantitative estimate of corrosion. The loss in weight method has been used most extensively in determining the amount of corrosion incurred by a sample after a given duration of exposure. The accuracy of measurement by this method depends on the complete removal of corrosion products without loss of uncorroded base metal. This is extremely difficult in many cases and is practically impossible when the corrosive agent penetrates the metal. Grain boundary penetration by a corrosive agent can drastically alter the physical properties of a material without appreciably changing its weight.

The purpose of the present paper is to place on record an alternate quantitative method of measuring the extent of corrosion which is currently in use with considerable success in Brookhaven National

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* This paper was presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Metallurgical Engineer, The Babcock & Wilcox Co., New York, N. Y.

[2] H. H. Uhlig, "The Corrosion Handbook," John Wiley & Sons, Inc., New York, N. Y., pp. 955–957 (1948).

Laboratory.[3] While this method was developed primarily to measure the amount of corrosion by molten metals, it is generally applicable to all kinds of corrosion and oxidation tests.

Materials and Procedure

A broad program of corrosion testing, to determine the relative stability of structural materials in liquid bismuth-base metals at elevated temperatures was initiated at Brookhaven National Laboratory in 1951. The construction materials under study included Armco iron, carbon steel, a graded series of high-temperature alloy steels, and several nonferrous metals. These materials were exposed to the action of molten bismuth alone and in combination with lead, tin and other liquid metals at 1000 F and higher. Static, dynamic (natural circulation loop), and stress-corrosion tests were included in the test program.

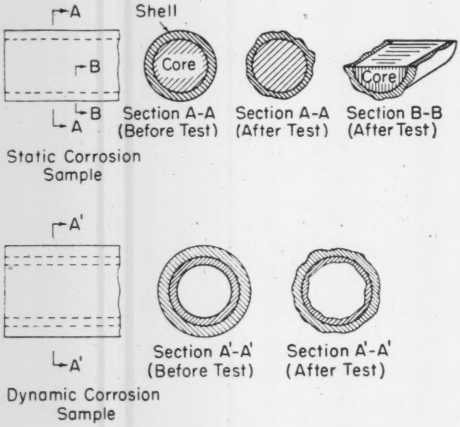

Fig. 1.—Corrosion Test Specimens.

Since the purpose of these tests was to indicate the service life that may be expected from the various construction materials, it is desirable to evaluate the results quantitatively by direct measurement of penetration after a certain period of exposure. For various reasons, notably the nature of the corrosive medium, none of the methods usually employed for this purpose was considered suitable for measuring the extent of attack by liquid metals. However, this was accomplished by means of a specially designed sample in conjunction with the procedure which is briefly described below.

Specimen:

The samples used in this investigation were obtained from plate, bar stock, or tubing of adequate thickness. The two types of corrosion samples used in the static and dynamic tests are shown diagrammatically in Fig. 1. The sample for static corrosion tests is approximately $\frac{3}{4}$ in. long and consists of a precision ground solid cylindrical "core" which is cold press-fitted into a similarly machined hollow cylinder or "shell" of the same material. While any reasonable ratio of core-to-shell size may be used, it was found expedient in these tests to standardize the core of all samples at 0.200-in. diameter and the shell at 0.250-in. outside diameter (total exposed surface area about 0.650 sq in.). The machining tolerances of the cores and shells from each material were carefully determined to ±0.0001 in. with the aid of a Pratt & Whitney supermicrometer, and these tolerances were taken into account in the measurement of average and maximum penetration.

The novel feature in this type corrosion sample is the core which, except at the ends, obviously is never in contact with, and therefore is not affected by, the corrosive medium. The unaffected core provides a constant reference circle from which the maximum as well as the average attack, suffered by the test section, may be accurately measured. The photographs in Fig. 2 show typical cross-sectional views of static corrosion test samples before and after exposure.

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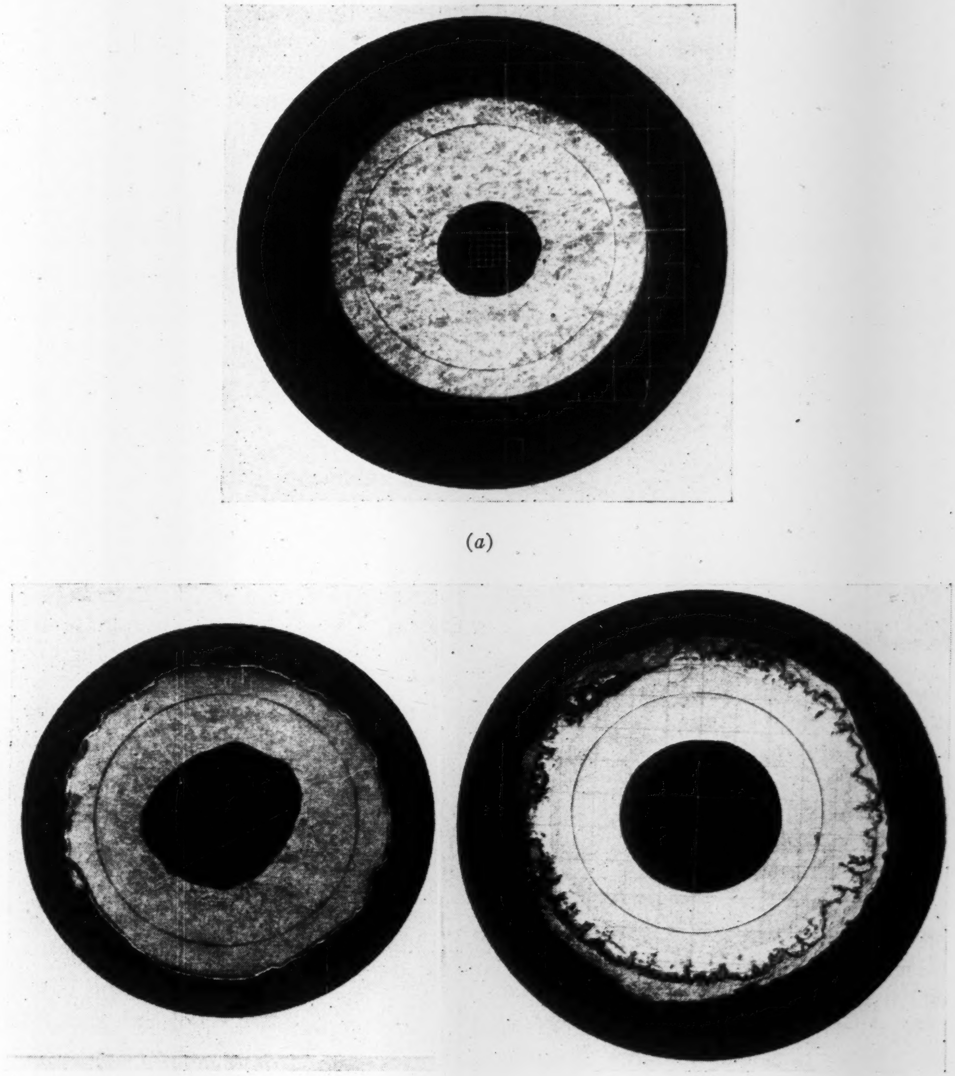
[3] M. A. Cordovi, *BNL Report No. 179* (Secret), Brookhaven National Laboratory, March, 1952.

The dynamic corrosion test sample (Fig. 1) is provided with a central hole which permits the flow of liquid through and around the sample. It is assumed, therefore, that results obtained with this type specimen would approximate corrosion damage occasioned in a fluid system in service.


(a)

(b)

(c)

FIG. 2.—Cross-Section of Sample.

(a) Prior to Testing.
(b) After Testing. Note Penetration.
(c) After Testing Showing Compound Formation at Metal Interface.

NOTE.—The black area in the center of the samples is inked prior to photographing, in order to provide a better background for the grid lines of the Whipple disk. These lines are used to determine the magnification of the photographs.

Procedure:

In all cases the following test procedure is employed. The sample is placed in a crucible made of graphite, this material having been shown by tests to be inert toward molten bismuth at temperatures of the order of 1000 F. Next, a graphite plug, provided with a central hole to permit free access of the liquid metal to the sample, is fitted into the container. The function of the plug is to prevent the sample from floating, due to its lower density compared to that of bismuth. The bismuth is then added in the form of small lumps (total charge 100 to 120 g) to fill the crucible to approximately 80 per cent of its volume. The charged crucible is inserted and sealed in a glass container (Pyrex or Vycor), the open end of which is connected to a vacuum pump (Fig. 3). A split-type vertical tube furnace is positioned around the container and the bismuth is melted under vacuum at 650 to 700 F. This temperature is maintained for several hours to insure thorough degasing of the liquid metal. At a vacuum gage reading of 0.1 μ mercury the glass container is sealed off with an oxy-acetylene torch and the charged capsule is quickly transferred into a tubular furnace which has been preheated to the required test temperature.

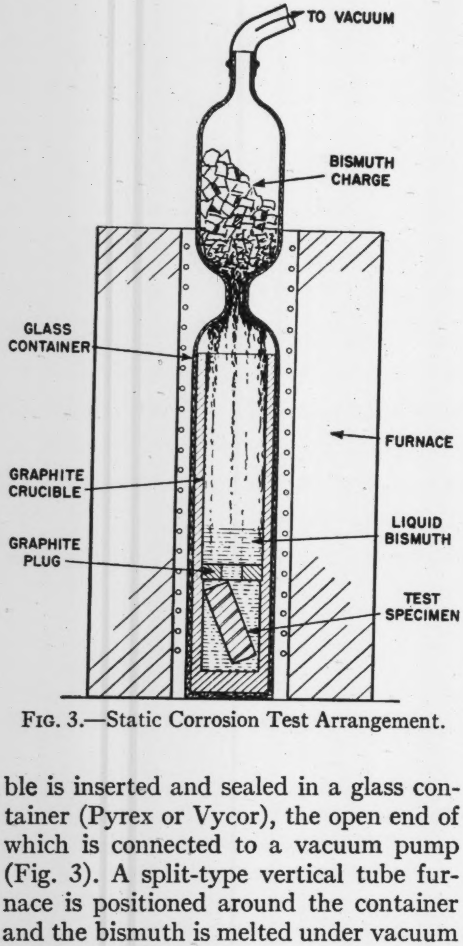


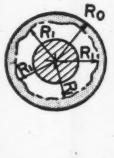
FIG. 3.—Static Corrosion Test Arrangement.

At the end of the test period, the container is allowed to cool to room temperature and the solidified metal slug, containing the sample, is removed and immersed in mineral oil at about 600 F. In due time the bismuth slug melts and the sample is released. It is removed from the oil bath, carefully dried and, after visual examination, is sent to the metallographic laboratory for further processing. The bismuth slug, in turn is sent to the chemistry laboratory to determine the solubility of the principal constituents of the specimen material.

One or more transverse sections, each approximately $\frac{1}{4}$ in. long, are cut from the sample with a cut-off wheel. These sections are chromium plated on the corroded perimeter, mounted in bakelite, and are prepared for metallographic examination in the usual manner. The specimen sections are then photographed through a grid of known dimensions (0.14 mm) which is etched on a thin glass slide (Whipple disk), Fig. 2. The photographs are enlarged between 20× and 30× and printed on Kodak Resisto Rapid paper, which exhibits remarkable resistance to distortion during processing. By simple geometric construction, the center of the core section is determined on the print and a number of radii are drawn at random through the core to the outside diameter of the shell. The over-all and maximum penetration are determined by the expressions:

$$P_{\max} = (R_0 - R_1)\max \qquad (1)$$

$$P_{\text{avg}} = \sum_{1}^{n} \frac{(R_0 - R_1)}{n} \qquad (2)$$



where:

P = penetration,
R_0 = original outside radius of the shell,
R_1 = radii intersecting random points on the corroded perimeter of the shell, and
n = number of radii.

Average penetration has been checked in many instances with a polar planimeter on the basis of the relationship:

$$dA = \pi (R_0^2 - R_A^2) \qquad (3)$$

where:

dA = area of metal corroded, and
R_A = average final radius of exposed shell surface.

From Eq 3

$$R_A = \sqrt{R_0^2 - \frac{dA}{\pi}}$$

and

$$P_{avg} = R_0 - R_A \qquad (4)$$

In general, there has been satisfactory agreement with the values of average penetration obtained by direct measurement, and consideration is being given to the use of the planimeter method alone in future work.

DURATION OF TEST

The duration of a laboratory corrosion test depends primarily on the nature and purpose of the test. In general, it is advisable to expose simultaneously a number of identical samples, under the same test conditions, so that one or more may be removed at intervals and the progress of corrosion thus determined. Since several of the experimental alloys were available only in very limited quantities, the above procedure could not be used in some of the static corrosion tests. In these cases an "interrupted" test procedure was followed. This procedure involves exposure of the sample to the action of liquid metal for an initial test interval of 500 hr, at the end of which a small section is cut from the sample and processed in accordance with the previously described laboratory and analytical procedure to determine the progress of penetration. The remaining portion of the sample is carefully cleaned, then replaced into a crucible with a fresh quantity of bismuth, and the container is reloaded in the furnace for an additional exposure of 500 hr. At the end of this period another section is cut off and the remainder of the sample is re-exposed to the action of the corrosive agent for a third period of 1000 hr. The total accumulated test time is therefore 2000 hr.

Comparative tests have shown that the total average and maximum penetration obtained after several exposures is of the same order of magnitude as the amount of corrosion incurred by the sample after a single exposure for the same total number of hours. While the results of the "interrupted" tests seem to be valid in this particular case, this should not be interpreted as a general endorsement of such a procedure. Its validity should be ascertained in every case for the specific test conditions considered.

CONCLUSIONS

The test method described herein is equally applicable to both static and dynamic corrosion tests and is especially suitable for high-temperature oxidation tests. It offers several distinct advantages over other available methods of measuring corrosion and may be briefly summarized as follows:

1. It affords the possibility of measuring the extent of maximum as well as average attack by a single set of determinations.

2. The extent of corrosion is determined by a simple direct measurement, the accuracy of which is not contingent on the amount of corrosion products or on the mode of attack.

3. The photographic procedure provides a useful permanent record of the experimental data obtained. The photo-

graphs may be measured simultaneously by a number of investigators at different laboratories, thereby substantially reducing the possibility of personal or incidental error.

4. The mode of attack, that is, whether uniform or localized, is readily apparent from the photographed sectional view of the test sample. The use of a microscope for that purpose, therefore, may be dispensed with in many cases.

Acknowledgment:

The assistance received from members of the Metallurgy Department of Brookhaven National Laboratory who participated in the conduct of this investigation is gratefully acknowledged. The author also wishes to express his appreciation to the Brookhaven National Laboratory for permission to publish the details of this work.

DISCUSSION

MR. F. L. LAQUE.[1]—In his description of his technique Mr. Cordovi quite properly emphasizes the value of metallographic examination in determining the extent of damage by corrosion, especially when there has been localized subsurface penetration not obvious from ordinary inspection or reflected in extent by weight change measurements.

Although the novel scheme he has devised for preserving a base line for measurements of the depth of attack has merit, its advantage over simpler specimens may be important in only a limited number of cases.

In our studies of deterioration of metals exposed to attack by gases or liquids at elevated temperatures, we regularly depend on metallographic examination to determine the nature and extent of attack. For this purpose we have secured satisfactory results with simple flat specimens of known original thickness exposed so that each of the major surfaces is exposed uniformly to the corrosive attack. It is not difficult to examine typical cross-sections at appropriate magnification after exposure and by measuring the thickness of unattacked metal to determine the maximum and average depth of attack. Such calculations will be in error only to the extent to which attack may have progressed more from one surface than from the opposite surface—an effect which is not likely to be great when both surfaces have been exposed equally to the same corrosive action. The principal merit of Cordovi's method would appear to be in the avoidance of errors from this source. There would be no advantage of one method over the other with respect to the choice of a truly representative cross-section for examination where there is a variation in attack along the length of a specimen.

MR. SAM TOUR.[2]—The corrosion test specimen geometry developed by M. A. Cordovi in connection with studies of corrosion by molten metals should be useful for corrosion testing of metals in media other than molten metals. It may be useful for tests in service installations as well as in laboratories.

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[1] In charge, Corrosion Engineering Section, Development and Research Division, The International Nickel Co., Inc., New York, N. Y.

[2] Sam Tour and Co., Inc., New York, N. Y.

MR. M. A. CORDOVI (*author's closure*). —The author wishes to thank Messrs. Tour and LaQue for their comments. Our own experiences support Mr. LaQue's statement that under conditions involving total immersion in liquids or uniform exposure to gases at elevated temperatures, the extent of attack on metals may be determined with a fair degree of accuracy on thin flat specimens of uniform thickness by metallographic examination. In addition to possible sources of error pointed out by Mr. LaQue, such a procedure obviously is unsuitable where determination of the extent of metal deterioration in heat transfer systems is involved. In such applications the inside and outside surfaces of tubular elements are practically never exposed to the same corrosive environment and temperature conditions. Such conditions can be accurately evaluated, however, by using a sample of the type shown in Fig. 1 (bottom). The photographic technique described in the paper makes possible the use of full size specimens which may be exposed under actual field operating conditions and the results evaluated as conveniently and accurately as on specimens of this same design which have been tested in the laboratory.

LOAD-DEFLECTION RELATIONSHIPS IN SLOW-BEND TESTS OF CHARPY V-NOTCH SPECIMENS*[1]

By R. Raring[2]

Synopsis

Load-deflection diagrams of slow-bend tests, at temperatures through the transition range of Charpy V-notch specimens of quenched-and-tempered and of pearlitic steels representing a carbon range of 0.01 per cent to 0.63 per cent and a tensile strength range of 48,000 psi to 152,000 psi are shown. Characteristics of the diagrams and of the development of the crack are observed. Results are compared, on the basis of energy absorbed and of transition temperature, with those of impact tests of the same steels. Some correlation between the slow notch-bend tests and tension tests is shown.

In the conventional notch-bend impact test of metals, results are expressed in energy units absorbed in effecting fracture of a specimen of arbitrary dimensions. In some instances, additional information is obtained by measuring the lateral expansion or contraction of the specimen or, in the case of iron and steels, by observing the amounts of fibrous or crystalline area on the fracture face. No data, however, on the load-deflection realtionship are acquired. Thus, it is entirely possible that two materials could absorb the same amount of energy, and therefore be indistinguishable in the impact test, yet differ greatly in the load they sustained and in the deflection they suffered during the course of the test. Also, the load and deflection at which the crack starts and the manner of its extension are not revealed in the results of the conventional test.

As would be expected, these deficiencies of the impact test gave rise to many investigations, especially during the first quarter of the century when the conditions of test and the dimensions of the specimens now in common use were in process of development and standardization. Mention of most of these early investigations is omitted here because they deal with a wide variety of materials and specimens, tested usually at room temperature, and are therefore difficult to interpret, and also because a comprehensive critique by Fettweis (**1**)[3] of such investigations prior to 1929 is available in English translation. More recent investigations in the U.S.A. showed marked differences in the load-deflection diagrams of slowly loaded Izod specimens of various materials (**2**, **3**). There are very few data, however, showing the effects of structure, composition, or strength level on the load-deflection relationship, or on the characteristics of formation and extension of the crack in the frequently used Charpy V-notch specimen tested either by impact or by slow-bending. The tests reported herein were performed, therefore, to obtain information concerning these factors in slow-bend tests of Charpy V-notch specimens, with the hope that such data might be helpful to the understanding of this specimen.

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* Presented at the Fifth-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Opinions or assertions contained herein are private ones of the author and are not necessarily those of the Navy Department.

[2] Acting Head, Ferrous Alloys Branch, Metallurgy Division, Naval Research Laboratory, Washington, D. C.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1049.

MATERIALS

The steels were chosen to represent a wide range of compositions and properties. In order to make possible a comparison of the slow-bend test with the impact test, only steels for which the energy-temperature relationship in the impact test had been determined were selected.

TABLE I.—COMPOSITION AND MECHANICAL PROPERTIES OF STEELS.

Steel	Composition, per cent						Tensile Strength, psi	Yield Point, psi	Reduction of Area, per cent	Elongation in 1.4 in., per cent
	C	Mn	Si	P	S	Ni				
No. 1	0.01	0.98	0.22	0.011	0.02	...	48 000	30 000	85.8	48.5
No. 2	0.22	0.96	0.21	0.010	0.02	...	71 500	45 200	65.7	38.6
No. 3	0.29	1.01	0.33	0.006	0.02	...	81 400	52 800	61.1	33.2
No. 4	0.43	1.04	0.28	0.006	0.017	...	96 300	51 200	53.1	27.8
No. 5	0.53	1.04	0.27	0.005	0.016	...	106 000	52 500	49.0	25.7
No. 6	0.63	0.99	0.26	0.004	0.016	...	121 100	55 200	34.6	18.2
No. 7	0.31	1.01	0.22	0.001	0.017	2.72	97 500	65 200	65.7	35.0
No. 8	0.35	0.99	3.06	0.004	0.02	...	121 500	82 100	45.7	28.6
No. 9	0.31	1.01	0.31	0.006	0.016	...	122 000	111 000[a]	66.0	22.8
No. 10	0.30	2.22	0.24	0.007	0.02	...	131 300	116 100[a]	60.0	19.3
No. 11	0.63	0.99	0.26	0.004	0.016	...	152 000	137 000[a]	49.0	16.5
No. 12	0.30	0.20	0.00	0.010	0.020	...	60 900	32 500	57.0	35.5[b]
No. 13	0.18	0.40	0.04	0.011	0.035	...	58 000	31 000	65.0	37.0[b]

[a] 0.2 per cent offset yield.
[b] Elongation in a 2-in. gage length.

Steels Nos. 1 through 11 were from silicon-aluminum killed laboratory heats which were melted in a 300-lb induction furnace, cast in 65-lb ingots, and forged to $\frac{5}{8}$-in. square bars. Specimen blanks were cut from these bars and normalized at 1650 F. Steels Nos. 1 through 8 were reheated to 1650 F and slowly cooled (25 F per min) to 800 F; steels Nos. 9, 10 and 11 were reheated to above the critical temperature, quenched in water, and tempered at 1000 F.

Steels Nos. 12 and 13, which were obtained through the courtesy of the Ship Structure Committee and the National Bureau of Standards, represent $\frac{3}{4}$-in. thick steel plates from merchant ships which suffered brittle fracture in service. Steel No. 12 is from a plate in which the fracture originated; steel No. 13 is from a plate through which a brittle crack passed but in which it neither originated nor terminated. The Charpy specimens from these ship-plate steels were longitudinal, with the notch parallel with the thickness direction of the plate.

The composition and the mechanical properties of all the steels are summarized in Table I. Tensile properties were determined by tests of specimens 0.357 in. in diameter with a gage length of 1.4 in., with the exceptions of steels Nos. 12 and 13, for which specimens 0.505 in. in diameter with a 2-in. gage length were used.

TEST METHOD

Charpy V-notch specimens conforming with the dimensions specified by ASTM standards[4] were used. The bars were supported horizontally by a fixture on the platen of a hydraulic testing machine and were loaded by a ram fastened to the fixed head of the machine. All dimensions of the supporting fixture and loading ram were made to conform with those specified for the anvil and striking hammer in the Charpy impact test.[4] The supporting fixture was contained in an insulated tank, so that the specimens could be tested while totally immersed in a liquid. In conducting tests at temperatures other than room temperature, the tank was filled with either glycerin, water, alcohol, or freon 12. To obtain the desired test temperature, the appropriate liquid was cooled either by direct additions of solid CO_2 or by liquid nitrogen introduced into a copper heat-exchange coil submerged in the tank, or was heated by electric-resistance immersion heaters.

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[4] Tentative Methods of Impact Testing of Metallic Materials (E 23 - 47 T), 1949 Book of ASTM Standards, Part 1, p. 1287; Part 2, 1035.

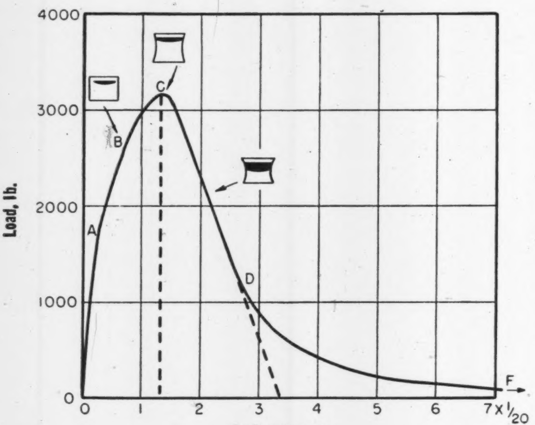


FIG. 1—Load-Deflection Diagram, Steel No. 5 at 150 F.

The specimens were loaded at a deflection rate of 0.1 in. per min. The load-deflection diagram was automatically recorded by a microformer-type deflectometer actuated by the change in the distance between the fixed head and the moving platen of the testing machine. The energy absorbed to any specific deflection or to fracture was calculated from planimeter readings of the area under the load-deflection curve.

The testing machine was hydraulically operated and had a full-scale load range of 6000 lb. Deflection magnification was 20×. Temperature measurements were made with either thermometers or copper-constantan thermocouples.

RESULTS

Figure 1, the load-deflection diagram for steel No. 5 at 150 F, illustrates characteristics which were found to be common to all the steels, with certain exceptions which will be noted below. The initial load, to point *A*, causes an approximately directly proportional relationship between load and deflection. The strain to this point is essentially elastic. Plastic yielding commences at point *A*, and from this point the slope gradually decreases to the maximum load.

The first evidence of the crack is observed approximately at point *B*, and such cracks always occur at the root of the notch near the midpoint. The exact location on the curve at which the first crack occurs is not determinable with precision, for its detection is considered to be sensitive to the finish at the notch root and to the care used in searching for it. However, even with the unaided eye, the first crack can readily be seen well before the maximum load is reached.

The crack grows laterally between points *B* and *C*, until at the maximum load a crescent-shaped crack extends completely across the specimen. These observations are illustrated by the schematic drawings in Fig. 1 and by the photograph in Fig. 2. Figure 2 represents a specimen of steel No. 5 which had been loaded to the maximum load in the ductile range. The specimen was removed from the testing machine and carbon ink inserted in the crack. It was then cooled to −320 F and fractured by impact. This coincidence of maximum load and the full lateral growth of the crack confirms observations of Schwinning and Matthaes (4) who used 20 by 20-mm bars with the standard DVM notch (45-deg angle, 8 mm deep, 0.5 mm radius). However, Cornu-Thénard (5) and Maurer and Mailänder (6), who used specimens with less acute notches, found that the crack first appeared at the maximum load rather than before it.

From point *C* to point *D* the crack deepens while extending down the sides of the specimen. The mechanism by which deflection occurs in this part of the curve seems to differ in kind from that of the previous part. Between points *A* and *C* the deflection is associated with bending strain in a relatively large volume of metal extending to as much as $\frac{1}{4}$ in. from the notch, whereas the deflection between points *C* and *D* is achieved through a tearing-like mechanism which causes an intensification of the strain in the metal immediately adjacent to the fracture.

At point *D*, the slope begins to decrease rapidly and the curve forms a tail terminating in fracture at a very low load, well to the right of point *F*. It is interesting to note that Wagner and Klier showed a slow-bend diagram (7) which suggests that this portion of the curve can be eliminated by means of the modification suggested by Schnadt (8), in which a hole is drilled through the compression side of the bar and a hardened pin inserted.

As can be seen in Fig. 1, the work to maximum load is somewhat less than half of the work to fracture. In this respect, the Charpy V-notch specimen is similar to the keyhole specimen used by Cornu-Thénard (7) or to the 12-in. wide center-notch specimen (9), but

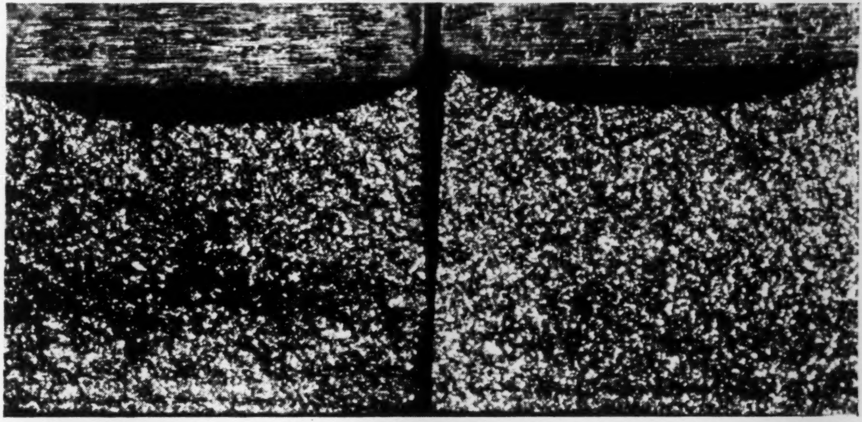


FIG. 2.—Face of Fracture of Specimen of Steel No. 5 Loaded Slowly to Maximum Load, Then Fractured by Impact at −320 F.

differs from the Navy Tear Test in which the work to maximum load constitutes about two thirds of the total work (10).

Effects of Carbon in Pearlitic Steels:

Figure 3 shows load-deflection diagrams of six steels which differ in carbon content, but which are similar in that they all have approximately the same pearlite spacing. It will be noticed that steel No. 1 differs from the higher-carbon steels. This is the type of material which stops the hammer or pulls through the anvil supports without fracturing in the conventional impact test. Steel No. 1 did pass a maximum load and showed a slight decrease before the deflection range of the bend jig was reached, but it failed to show the crack formation and tearing-like separation characteristic of the descending portion of the curves of the higher-carbon steels.

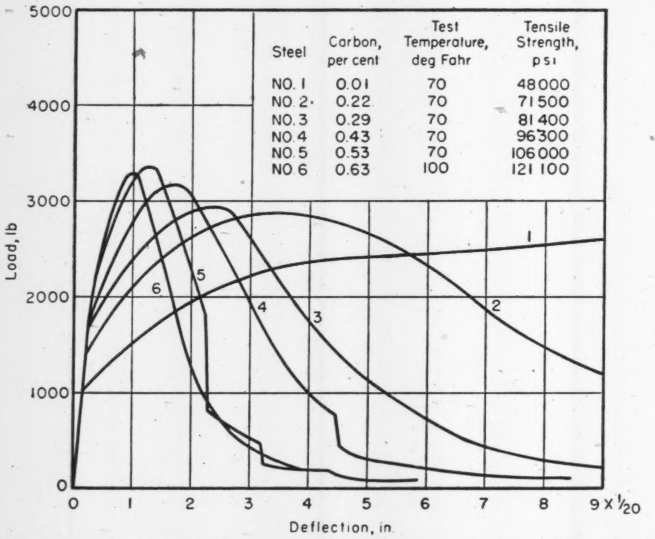
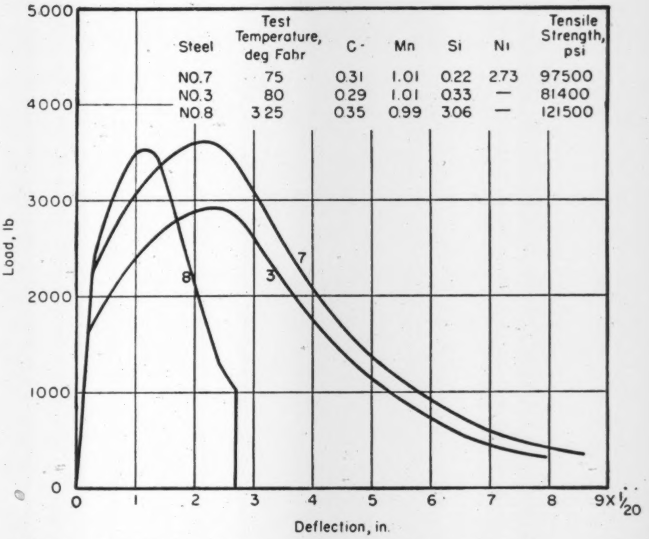


FIG. 3.—Load-Deflection Diagrams Showing Effects of Carbon in Pearlitic Steels.

The increase in strength of the steel with increase in carbon content is reflected in the yield load, but not fully in the maximum load. The deflection at maximum load is decreased, and the slope of the descending part of the curve is increased by increase in carbon content; both of these changes have the effect of decreasing the work to fracture. All of the curves of Fig. 3, as do subsequent curves of this paper, with the exception of that of steel No. 1, display an evident trend: namely, as the deflection at maximum load decreases, the slope of the descending part of the curve increases. This trend will be discussed later.

Effects of Silicon and Nickel:

Figure 4 illustrates the effects of the addition of nickel and of silicon to pearlitic steel. The three steels have approximately the same pearlite spacing and are of nearly the same composition, with the exception of the added silicon or nickel. Unlike carbon, the addition of nickel increases the maximum load in the bend test by the same proportion that it increases tensile strength. The deflection at maximum load is not appreciably changed, but the work to



Steel	Test Temperature, deg Fahr	C	Mn	Si	Ni	Tensile Strength, psi
NO.7	75	0.31	1.01	0.22	2.73	97500
NO.3	80	0.29	1.01	0.33	—	81400
NO.8	325	0.35	0.99	3.06	—	121500

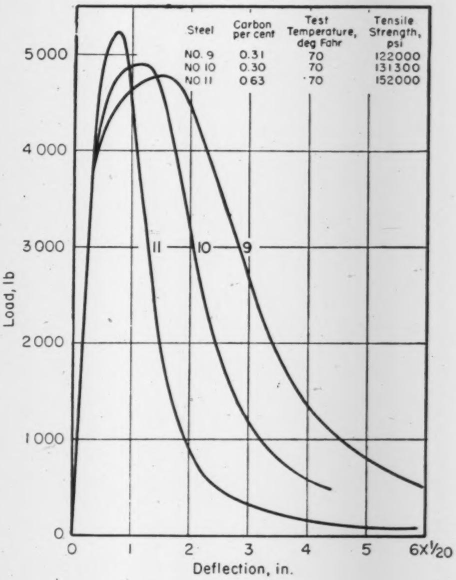
FIG. 4.—Load-Deflection Diagrams Showing Effects of Nickel and Silicon.

fracture is increased as a result of the increase in the height of the curve.

Silicon decreases the deflection at maximum load and increases the height of the curve. However, when areas are compared, it is evident this increased strength is insufficient to compensate for the loss in ductility; consequently silicon decreases the maximum energy, as has previously been shown to be so in the impact test (11). It should be noted, however, that the tests of steels Nos. 3 and 8 were made at different temperatures. The high temperature of the test of the silicon steel was necessary in order to assure ductile behavior.

Quenched and Tempered Steels:

The load-deflection diagrams of three quenched-and-tempered steels, (Nos. 9, 10, and 11) are shown in Fig. 5. It will be noted that these steels reach considerably higher maximum loads than do pearlitic steels. For example, the pearlitic steel No. 6 (Fig. 3) and the quenched-and-tempered steel No. 9 (Fig. 5) have the same tensile strength, yet the maximum load of the quenched-



Steel	Carbon per cent	Test Temperature, deg Fahr	Tensile Strength, psi
NO. 9	0.31	70	122000
NO 10	0.30	70	131300
NO 11	0.63	70	152000

FIG. 5.—Load-Deflection Diagrams of Quenched-and-Tempered Steels.

and-tempered steel is 45 per cent higher than that of the pearlitic steel in the bend test. Figure 5 also suggests that with quenched-and-tempered steels, as with the pearlitic steels (Fig. 3), an increase in tensile strength is not reflected in a proportional increase in maximum load in the bend test, but does result in a marked decrease in deflection at maximum load and, consequently, a decrease in work to fracture.

Effects of Temperature on Load-Deflection Diagram:

Figure 6 shows the effect of temperature on the load-deflection diagram of steel No. 3. For simplicity, diagrams for only six temperatures are shown, but tests at intermediate temperatures conform to the general trend.

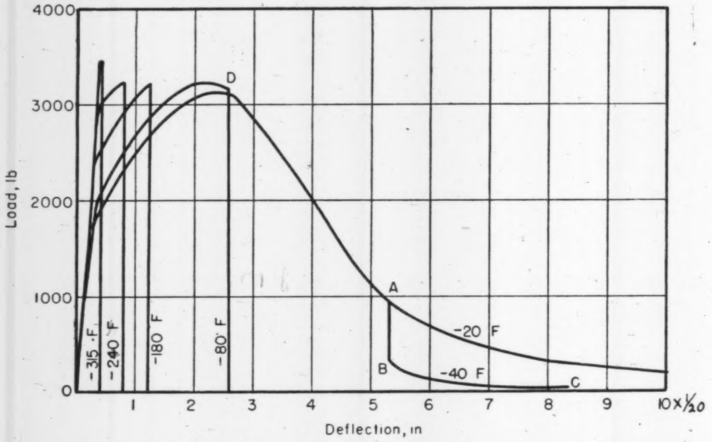


FIG. 6.—Load-Deflection Diagrams of Steel No. 3 at Various Temperatures.

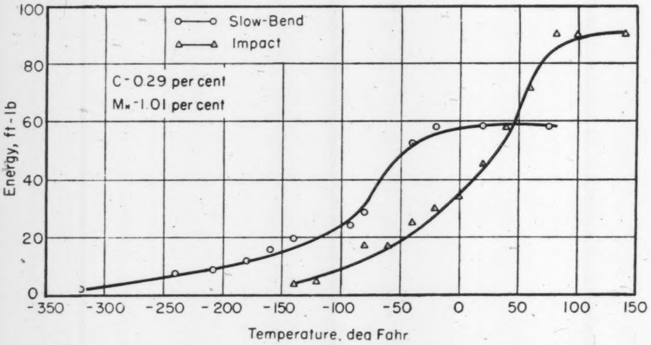


FIG. 7.—Energy-Temperature Relationship for Steel No. 3.

Above the temperature at which the first evidence of crystalline fracture appears (for example, −20 F), the diagram conforms with the general description given previously. In the test at −40 F, a cleavage separation occurred at point *A*, the load dropped instantly to point *B*, and then decreased along line *B–C* roughly parallel to the −20 F curve. The brittle separation at point *A* is evidenced in the broken bar by the familiar patch of crystalline fracture. Some specimens show two or more abrupt drops in the load, separated by a gradual slope in the diagram, and the fracture faces of such specimens contain isolated patches of crystalline fracture separated by areas of fibrous fracture. Schwinning and Matthaes (4) showed very similar steps in slow-bend diagrams of notch-bend tests. The specimen tested at −80 F developed a brittle crack immediately after passing through the maximum load, but at this point the elastic energy contained in the bar was sufficient to propagate the crack completely through the specimen. The fibrous area of the fracture in this specimen tested at −80 F was approximately of the shape and size of the dark crescent-shaped area shown in Fig. 2 and constituted between 5 and 10 per cent of the fracture face. Tests conducted at temperatures lower than −80 F developed brittle fracture before maximum load was reached, that is, on the ascending part of the curve. The yield load, it will be noticed, increased as the temperature was lowered, until finally at −315 F no plastic yielding occurred and the deflection was essentially elastic. It is remarkable that the maximum loads reached in the tests at the several temperatures varied very little. The effects of temperature on the load-deflection

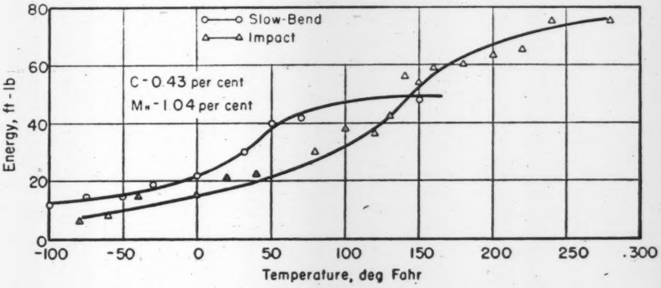


FIG. 8.—Energy-Temperature Relationship for Steel No. 4.

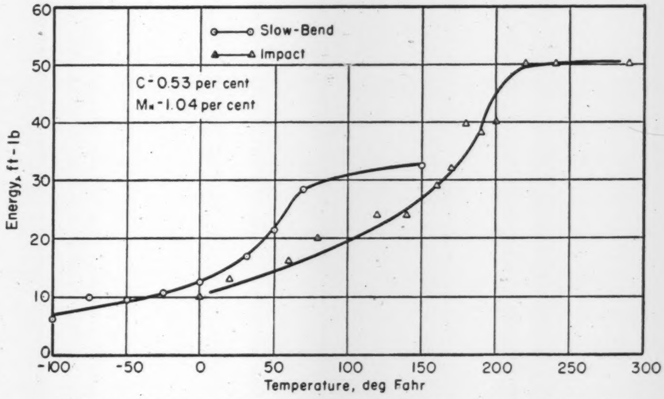


FIG. 9.—Energy-Temperature Relationship for Steel No. 5.

diagrams of the other steels were similar to those shown in Fig. 6.

Effects of Deflection Rate:

A study of the effect of deflection rate on the load-deflection diagram was not within the scope of this investigation, but such studies have been made and show that in some steels, impact loading, as compared with slow loading, results in higher load-deflection curves, increases the work to fracture in the ductile mode, and raises the transition temperature (4). Since data from Charpy V-notch impact tests of all the steels were available, it was possible to compare the energy-temperature relationship in both impact and slow-bending. Such comparisons are shown in Figs. 7 through 14.

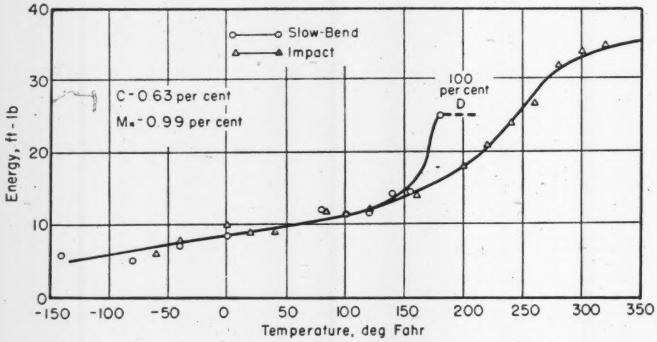


FIG. 10.—Energy-Temperature Relationship for Steel No. 6.

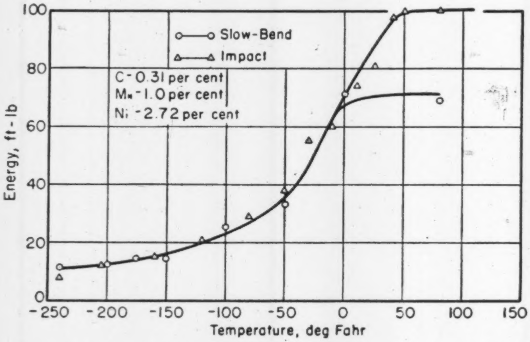


FIG. 11.—Energy-Temperature Relationship for Steel No. 7.

These figures show that the maximum energy absorbed in impact is one third to one half again as great as it is in the slow-bend test. The transition temperature is generally raised by the increase in deflection rate, but the degree of the change is widely variable and, evidently, dependent upon the material and the criterion for transition temperature. To contrast extreme examples, the 15-ft-lb transition temperature of steel No. 12 (Fig. 13), which is a ship plate steel that failed in service, is lowered 160 F by the change in deflection rate, but the transition temperature, by the same criterion, of steel No. 7 (2.72 per cent Ni) is not changed (Fig. 11).

Figures 13 and 14 also show the energy-temperature relationship of steels Nos. 12 and 13, as determined by impact of lower striking velocity than that of the conventional impact test.[5] It will be noticed that in the low-energy regions of the curve, the intermediate deflection velocity had the effect of shifting the curve to a position intermediate to those of the standard impact and the slow-bend tests.

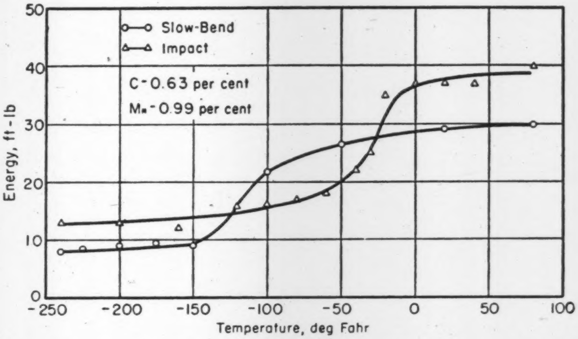


FIG. 12.—Energy-Temperature Relationship for Steel No. 11.

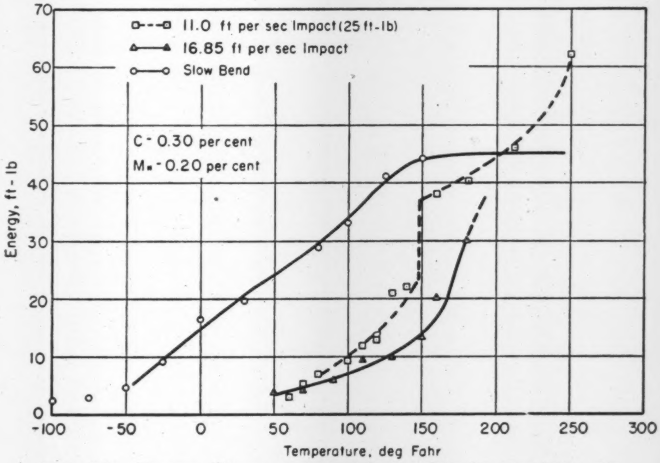


FIG. 13.—Energy-Temperature Relationship for Steel No. 12.

Correlation of Notch-Bend Tests with Tension Tests:

Frequent attempts have been made to show correlation between results of notch-impact tests and tension tests. Such correlations usually show scatter. Since the strain rates in the two tests are different and since strain rate is unquestionably an influencing factor, it might be expected that correlation would be better in comparison of results of slow notch-bend tests with those of tension tests.

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[5] The average deflection rate in these low-energy impact tests should be less than would be indicated by the striking velocities, for it will be noticed that the striking energy was 25 ft-lb, which was, in some instances, insufficient to fracture the specimen. In such instances, fracture was completed by additional blows; consequently the average deflection velocity would be less than the striking velocity indicated.

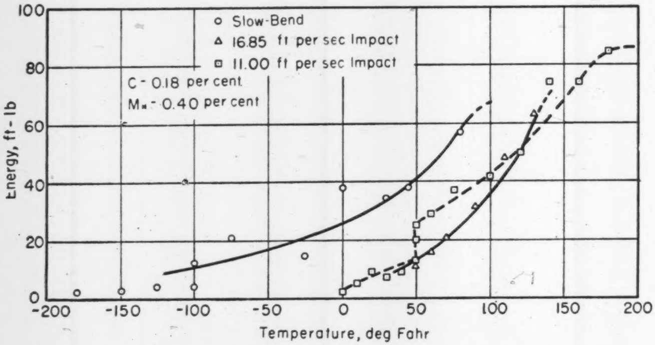

FIG. 14.—Energy-Temperature Relationship for Steel No. 13.

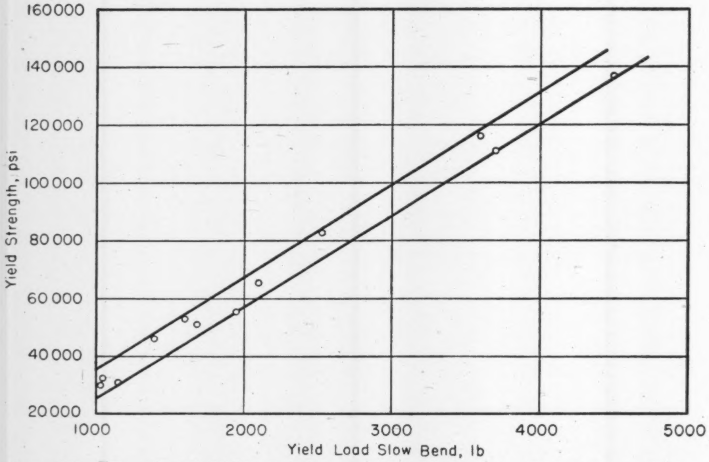

FIG. 15.—Tensile Yield Strength *versus* Yield Load in Notch-Bend Tests.

Figure 15 indicates a linear relationship, with some scatter, between the yield point, or the 0.2 per cent offset yield strength for steels which have no yield point, and the load at which a noticeable deviation from the elastic portion of the load-deflection curve in the slow notch-bend test occurred.

Figure 16 is a plot of the maximum energy absorbed in the slow notch-bend test against the specific energy to fracture in the tension test. This latter value was calculated by measuring the area under the true stress - true strain plot of tension test data, an area which MacGregor and Fisher have shown to correspond to the specific energy absorption at fracture (12). The points for pearlitic steels of 0.30 per cent or more carbon lie fairly close to a straight line, but the maximum energy in the bend test for steel No. 2 (0.22 per cent C) is very high. It is considered that this divergence is due to the fact—which can be surmised from Fig. 3—that the load-deflection curve of steel No. 2 deviates noticeably from the pattern of the curves of the stronger steels; the descending part of the load-deflection curve does not develop a constant slope soon after maximum load, but rather gradually fairs off into the tail of the curve. This suggests, as has been mentioned above, that fibrous fracture of Charpy V-notch specimens of very ductile steels differ in kind from, and should not be

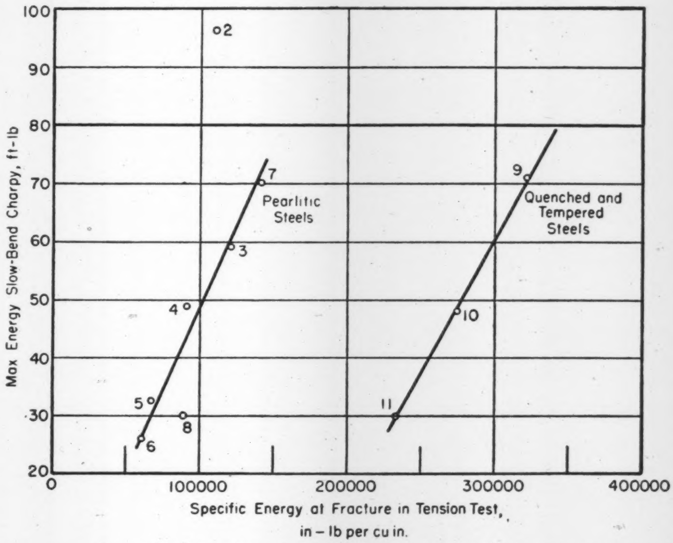

FIG. 16.—Maximum Energy in Slow-Bend Tests of Charpy V-Notch Specimens *versus* Work Under the True-Stress True-Strain Curve of Tension Test. Numbers Identify Steels.

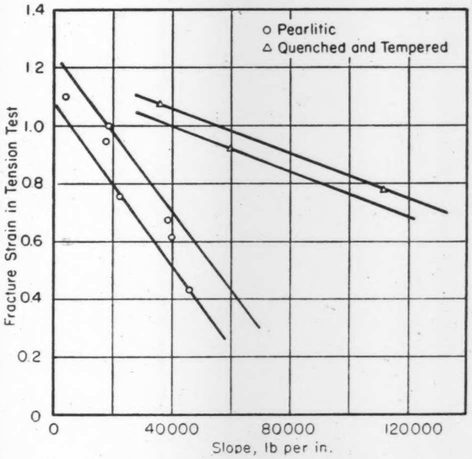

FIG. 17.—True-Stress at Fracture in Tension Test *versus* Slope in the Notch-Bend Test.

compared with, such fractures of less ductile steels. The maximum energy for steel No. 1 is not shown in Fig. 16 because the deflection of specimens of this steel exceeded the range of the bend jig, but it obviously would have been much higher even than that of steel No. 2. The point representing steel No. 8 lies well below the line, but this deviation might be explained by the fact that the bend test was conducted at +350 F and the tension test was made at room temperature.

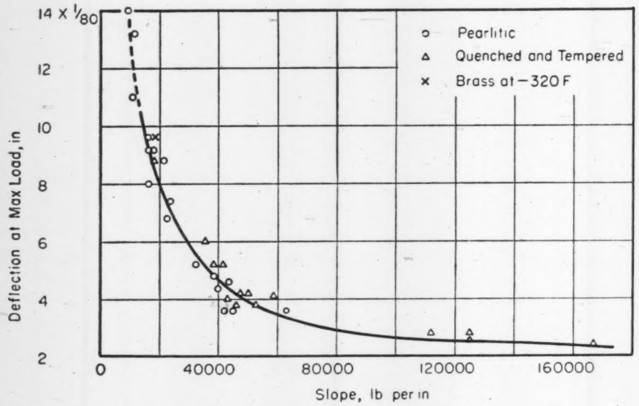

FIG. 18.—Deflection at Maximum Load *versus* Slope of Load Deflection Diagrams of Charpy V-Notch Specimens.

The specific energy absorption in the tension test of the quenched-and-tempered steels also varies lineally with maximum energy in the notch-bend test, but the curve, as compared with that of the pearlitic steels, is displaced in the direction of higher specific-energy absorption in the tension test. The slopes of the lines for pearlitic steels and quenched-and-tempered steels appear to be parallel.

Figure 17 is a plot of true strain at fracture in the tension test against the slope of the straight portion of the load-deflection diagram of the notch-bend test. The relationship appears to be linear, with different slopes for pearlitic and martensitic steels.

Similarity of Load-Deflection Curves:

Load-deflections diagrams of slow-bend tests of Charpy V-notch specimens show certain common characteristics and trends as the composition, strength, ductility, or structure of the material are varied. One such trend—the tendency for the slope of the straight portion on the descending side of the load-deflection curve to increase as the deflection to maximum load decreases—is represented graphically in Fig. 18. The points in this plot represent tests of both pearlitic and martensitic steels at temperatures from −100 F to +350 F. An isolated test of alpha brass at −320 F is also included. The broken line at the left end of the curve was so drawn because the steels represented by the last three points were soft, and the slopes and maximum loads could not be determined unequivocally.

DISCUSSION

It should be recognized that findings from slow-bend tests of Charpy specimens do not necessarily hold for impact loading. For example, it has been shown that, at least for some steels, the height of the load-deflection curve is raised, the maximum energy is increased, and the transition temperature is raised by increasing the deflection velocity from that of the slow-bend test to that of the conventional impact test (4). However, on the basis of the limited data available, it appears that the load-deflection curves under the two deflection rates, while not necessarily identical, are of the same general shape (4). It should also be recognized that the question as to which kind of test, fast or slow, more closely represents the condition obtaining during brittle failure of structures is not resolved to the unanimous satisfaction of all investigators (13).

In order to study the effects of deflection rate, the preferred experimental approach obviously would be to make load-deflection diagrams over a wide range of loading velocities. Such tests would require fairly involved instrumentation and were therefore outside the scope of the present investigation. Since impact data were available on the steels, it was possible to compare results from the two deflection rates in terms of transition temperature and maximum energy. Such comparisons (Figs. 7 to 12) clearly show that the effects of deflection rate are variable and can be large, shifting the transition temperature from 0 to 150 F in extreme cases. These results illustrate the commonly accepted conclusion that strain rate is an important variable in the determination of transition and emphasize the necessity of duplicating the strain rates that occur during service failures in any effort to correlate test results with brittle failure of steel structures.

One possible use of the load-deflection diagram is the indication of both notch strength and notch ductility. That the conventional impact test fails in this respect is evident from Figs. 3 and 5, which show that two steels (namely, Nos. 3 and 9) could absorb the same amount of energy, yet differ in their ability to sustain load. Thus, by its inability to indicate the relative contribution of strength and of ductility to energy absorption, the conventional impact test fails to develop data which could be of significance. The same deficiency obviously would apply to the tension test, if results were expressed solely in terms of the area under the load-elongation curve rather than the conventional parameters of strength and ductility.

In general, it is clear that the conventional impact test gives a result that can be considered to represent an integration of both strength and ductility. The load-deflection diagram makes possible at least a partial separation of these two properties. For example, it would seem that prior to the formation of the crack, the strength of the material controls the course of the curve, whereas the deflection at maximum load and the slope of the descending part of the diagram are associated with ductility. The maximum load appears to be influenced by both strength and ductility.

FINDINGS[6]

The following conclusions are indicated as a result of this investigation:

1. Load-deflection diagrams of slow-bend tests of Charpy V-notch specimens of various steels form family-like groups of curves with common characteristics.
2. The first ductile crack occurs in the root of the notch at the mid-point, well before the maximum load is reached.
3. The crack grows laterally as the load is increased, until it reaches the

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[6] Nos. 1 to 4 do not apply to very ductile steels.

edges of the specimen, at which time a maximum in the load-deflection curve occurs.

4. Soon after maximum load, the curve assumes a slope which is nearly constant until the load is reduced to about $\frac{1}{3}$ of maximum; in this stage the bar separates by a tearing-like mechanism.

5. Load-deflection diagrams of very soft steels differ in shape from those of stronger steels; this deviation is slight at about 0.20 per cent carbon but is very marked at 0.01 per cent carbon.

6. As carbon is increased in pearlitic steels, the maximum load in the notch-bend test is increased, but to a less degree than is the tensile strength.

7. The addition of nickel to pearlitic steel increases the maximum load in the notch-bend test by the same proportion that it increases the tensile strength.

8. The maximum load in the notch-bend test of quenched-and-tempered steel is markedly higher (45 per cent) than that of pearlitic steel of the same tensile strength.

9. Deflection at maximum load is decreased by additions of carbon and of silicon, but is not changed by additions of nickel.

10. As temperature is lowered in notch-bend tests, the yield load increases, the deflection at fracture decreases, but the maximum load increases slightly, if at all.

11. Maximum energy in impact tests is 30 to 50 per cent greater than in slow-bend tests.

12. The transition temperature in impact tests is from 0 to 160 F higher than in slow bend tests, depending upon the material and criterion for transition.

13. Yield load in the notch-bend test varies linearly with yield strength in the tension test.

14. Maximum energy in the slow-bend test varies linearly with the specific energy absorption in the tension test, but the curve for pearlitic steel is displaced from the one for quenched-and-tempered steels.

Acknowledgment:

The author gratefully acknowledges the helpful counsel of O. T. Marzke, Superintendent of the Metallurgical Division, Naval Research Laboratory, and of W. J. Harris, Jr., of the Metallurgical Advisory Board, National Research Council. The ship-plate steels were made available through the courtesy of Finn Jonassen, Technical Director, Committee on Ship Steel and Morgan Williams of the National Bureau of Standards. The chemical analysis, tension tests and standard Charpy impact tests of the two ship-plate steels were made by the National Bureau of Standards. George Gregg designed and constructed the bend jig and temperature control apparatus for the slow-bend tests, and conducted the tests.

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(5) Cornu-Thénard, "Etude experimentelle sur les essais au choe des barreaux entailles," *Revue de Metallurgy,* Vol. 17, pp. 536–554, 584–614 and 648–667 (1920).

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DISCUSSION

MR. WENDELL P. ROOP[1] (*by letter*).—That a careful study of load-deflection curves would be rewarding had become apparent to me before this paper demonstrated it. The author's work on Charpy bars is a good beginning. Similar work on other types of specimens should be done in an attempt to harmonize the data from the different types. In addition to the metallurgical variables which the author has studied, attention should also be given to the geometrical variables of load-pattern, proportion, and especially size.

The key problem is still that of predicting from laboratory tests the service behavior of full-scale structures. If a Charpy bar is ever to serve such a purpose it must be through comparison with some such intermediate geometry as that of a "wide plate," which serves as a specimen for material test when small but when blown up in strict similitude to larger scale factors can be regarded as an adequate though conventional scale model of working structure.

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[1] Sewell, N. J.

That the Charpy impact test gives only a gross energy value is from one point of view a defect and from another its chief merit. Since even moderate load always causes stress in an acute notch to rise high enough to call ductility into play, the stress intensity at which this occurs is not critically significant; high ductility can and does make up for low strength and *vice versa*. The product of the two is found with unmatched convenience in Charpy impact.

As the author points out and as MacGregor and Grossman confirm in their latest work,[2] the effect of strain rate is sensitive to metallurgical differences. The result is variations which appear to be erratic in tests in which the geometrical parameters are more strictly controlled than metallurgical differences. Also, since in Charpy impact and in ordinary service of ship structures the strain rates are surely different, and even in shock service may be quite different, disregard of these differences may lead to serious error in predicting service behavior from Charpy impact tests. I agree fully with the author's judgment that "it is necessary to duplicate the strain rates that occur in service failures in any effort to correlate test results with brittle failure of steel structures." I would go further and say that the rôle of strain rate in the two different items of energy may be quite different; in any case it must be better understood.

Energy to fracture is the sum of two terms of different nature, and no impact test can separate these as they must be separated if any sort of inference based on similitude is to be drawn.

What are these two different terms in the gross energy which an impact test fails to separate? To avoid preconceptions they will be labeled simply *A* and *B*. Energy *A* consists in the work done in inception of the fracture and Energy *B* in that needed to complete the rupture. The parting between them comes near, though perhaps not precisely at, the stage at which the slope of the load-deformation curve passes through zero value.

The author's description of the process of inception of the crack agrees with what I have seen in wide plates, but I am not sure that the process ends when the ends of the crack reach the ends of the notch nor that this stage corresponds exactly with the point of zero slope. However there is at least approximate correspondence.

So far as I know, no one has given a quantitative explanation of how the spread of the zone of plastic action is linked with the gradual enlargement of the incipient crack nor of how either of these is linked with the gradual reduction toward zero of the slope of the load-deformation curve. Also the rôle of strain hardening in the process is not wholly clear, although it is a fact that the load may continue to increase after the incipient crack has notably encroached on the net section. Is it this continued encroachment that cuts the slope eventually to zero? If so, notable differences should appear in the load-deformation curves between small and large specimens in which the encroachment of the incipient crack on the whole net section may be different in the ratio of a hundredfold.

Up to this point the Charpy bar and the wide plate act alike. Perhaps the effect of temperature in stage *A*, as seen in Fig. 6, is also similar in the two cases; previous tests of wide plates at low temperatures have not been enough in number to test such a surmise. Figure 6 shows that the constancy of peak load as temperature is reduced is accidental. At low temperatures the curve never reaches the point of zero slope, but is broken off abruptly by the incidence of brittle action. This also occurs in wide plates, but is not reflected in the reported values of "energy to maximum load." In the Charpy bars, as temperature is reduced, brittleness intervenes at an earlier stage; it is this shift that causes the gradual reduction of energy value with increased cold. Without cold brittleness the point of no slope would occur at higher loads and lower elongations as cold increases, and energy values at this point might be not much affected by cold.

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[2] C. W. MacGregor and N. Grossman, "Dimensional Effects in Fracture" *Welding Research Supplement*, Jan., 1952.

Is it worth the cost of an experimental project to find out whether this would also happen at low enough temperatures in wide plates? I doubt it. But at the moderate cold of service temperatures the load-elongation curve seems not much affected by cold. In small-scale plate specimens even the energy in term *A* is not much affected by cold; for some reason the abrupt intervention of brittle action does not occur if brittleness is measured by term *A*. It is only in larger specimens that cold cuts into the values of energy in term *A*. Further, it then does so more abruptly than in the Charpy bar, in which (as in Figs. 7 to 12) the loss of energy with reduced temperature is always gradual. I conclude that there is a marked difference in the mechanism by which cold affects term *A* in the Charpy and in the wide plate specimens, in addition to the differences in strain rate already mentioned.

The curves of Fig. 6 seem to be rather freely generalized. A stepwise progression like that in Curve 5 of Fig. 3 is more common in wide plate data in some steels than in others; it is not uncommon also in the rising branch of the curve.

Passing to term *B* and the falling branch of the curve, the significance of the initially steep and uniform downward slope and its correlation with deflection at maximum load, as plotted in Fig. 18, are not clear.

Conditions at this stage must be quite different from those in the wide plates, where the load peak is flatter and beyond it the curve pitches off downward with increasing slope. Perhaps autographic load recording would have made a difference, but surely nothing like the long tail exists. The differences between the two types of specimen seem to be greater with respect to term *B* than to term *A*.

What is meant by "maximum energy" in Fig. 16? Is it total energy to fracture or to maximum load? Proportionality of such a quantity with specific energy at fracture in round bars of a series of pearlitic steels suggests uniformity of strain pattern in the slow bend specimen, not only as between steels but also during the advance of strain intensity in a given test. If the average specific energy taken over the whole deformed region is a constant fraction of that at the apex of the notch, the pattern must remain stable as the intensity increases.

At a guess, I would say that the volume of metal sharing in plastic flow might be 0.01 cu in. Spread over this volume, 50 ft-lb gives an average of 60,000 in-lb per cu in., compared with 100,000 from the tension test. The metal in this small zone near the apex of the notch is thus worked well up toward its full capacity for absorbing energy. In a wide plate, on the other hand, the average specific energy in the gage volume of metal is at most a few per cent of that at fracture in the tension test.

Hechtman[3] gives data on the increase of strain energy with load at numerous points in a wide plate specimen taken at several load intervals up to the maximum. He reports that the energy at all points increases exponentially with load and that at different points in the strain field the rise is everywhere porportional to the average, ranging from $\frac{1}{2}$ to $3\frac{1}{2}$ times the average. This is direct confirmation of the stable strain pattern increasing only in intensity as load goes up. Up to the maximum load this seems possible, though rather unlikely, but how can it be possible beyond that point?

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[3] D. Vasarhelyi and R. A. Hechtman, "Welded Reinforcement of Openings in Structural Steel Members," *Welding Research Supplement*, April, 1952. See Fig. 12.

It is difficult also to imagine how the energy to maximum load (term A), as a fraction of the whole energy to fracture ($A + B$), can have the same value in two specimens as different as the Charpy bar, in which the advance after maximum load is a small fraction of an inch, and the wide plate in which the crack advances 10 to 100 times as far before rupture is complete.

Effects of size are not discussed by the authors. They seem to me to be crucial in their implications. Aside from all questions of impact load, eccentric action, and abruptness of temperature effect, the most obvious difference between Charpy bars and wide plates is one of size.

The definitive study of size effect has still to be made, but the fact is no longer doubtful that specific energy is lower and transition temperature higher as size increases among wide plates with initial geometry in strict similitude and with identical metallurgy. In my unpublished analysis of wide plate data a partial reason for this is found in the fact that elongation over gage length is less, in proportion to other linear dimensions, as size increases. But this still leaves us far from understanding the effect of size on transition temperature.

Efforts to study size effect in geometrically similar Charpy bars have been made, but, as I recall, they have not been decisive. In any case, no one wants to test big Charpy bars; the essence of their convenience lies in small size.

What is needed, rather, is a theory that will account for the form of the load-elongation curve. Possibly this need not, at least at first, account for item B of the gross energy; in the wide plates the effect of temperature on item B is closely correlated with indications of fracture appearance and in this way a "fracture transition" is well defined. The main difficulty is that most ships have long operated at temperatures well below this wide plate transition. Could the author make similar comment about fracture transitions as indicated by Charpy bars?

For item A of the gross energy, as it might be drawn from slow-bend Charpy data, let us ask for a theory which can account for the form of the load-deflection curve to maximum load. It should not exclude size-effect, but first of all should reproduce the trace of the curve as it bends over to zero slope. When we can take a true stress-strain curve from a round bar and predict the ductile performance of a Charpy bar, we will have gone a long way toward confirming the usefulness of the Charpy bar. To the Charpists, that is the goal I purpose.

MR. RICHARD RARING (*author*).—Comparisons of the load-deflection curves from Charpy specimens with those of notched wide plates are interesting, especially when made by one who has been so long and so intimately connected with the wide-plate tests as Mr. Roop. This interest is quickened, for obvious reasons, by the commonly held notion that the wide-plate specimen is a good representation of an engineering structure.

There are several questions raised in Mr. Roop's discussion which require comment. It is not completely accurate to say that the point of zero slope on the load-deflection curves in fully ductile tests will always occur at lower deflections as temperature decreases. In fact, Schwinning and Matthaes (4)[4] and Maurer and Mailander (6)[4] found lower ductility at higher temperatures, and they attributed the reduced deflection at the point of zero slope to strain aging.

Mr. Roop inquires as to the significance of the correlation between the deflection at maximum load and the slope of the descending part of the load-deflection curve (Fig. 18). Clearly, both of these parameters are parameters of ductility, and both reflect the ductility of the material in accordance with the relationship shown in Fig. 18. The fact that the plot of these parameters over such a very wide range of ductility—eighteen fold in the case of the slope and five fold in the case of deflection at maximum load—forms a smooth curve suggests a relationship between these two ductility parameters.

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[4] See references appended to the paper, p. 1049.

In Fig. 16, as elsewhere in the paper, "maximum energy" means the total energy absorbed by a fully fibrous fracture at temperatures immediately above the transition range.

Mr. Roop observes that most ships have long operated at temperatures well below the temperature at which fracture of wide-plate specimens of the steel from which the ships were made changes from fibrous to crystalline, and he asks if this finding would apply also to Charpy specimens. The answer is almost certainly yes. The very extensive investigation conducted at the National Bureau of Standards during the past decade shows that the 15-ft-lb level in Charpy V-notch tests of samples of ship steels which either did not fracture or in which fractures stopped, ranged from 0 to 100 F.[5] The 15-ft-lb level is almost always at a temperature below the temperature at which fracture appearance changes, so it seems reasonable to conclude that ships have operated at temperatures below the fracture-appearance transition temperature in Charpy V-notch tests of the steels from which they were made.

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[5] Williams, Meyerson, Kluge and Dale, "Investigation of Fractured Steel Plates Removed from Welded Ships," Ship Structure Committee Report No. NBS-3, June 1, 1951.

COMPRESSIVE, BEARING, AND SHEAR PROPERTIES OF SEVERAL NONFERROUS STRUCTURAL SHEET MATERIALS (ALUMINUM AND MAGNESIUM ALLOYS AND TITANIUM) AT ELEVATED TEMPERATURES*

By Dale D. Doerr[1]

Synopsis

This paper describes briefly the program in which the compressive, bearing, and shear properties were determined for (1) 24S-T3 aluminum alloy at room temperature and elevated temperatures between 212 F and 700 F, with exposure periods ranging from 0.5 to 1000 hr; (2) 75S-T6 aluminum alloy, FS-1h and MH magnesium alloy at room temperature and at elevated temperatures ranging from 300 F to 600 F, for exposure periods between 0.5 and 1000 hr; and (3) annealed and cold-rolled titanium at room temperature and several elevated temperatures between 400 F and 1000 F for exposure periods of 0.5 and 100 hr. These properties have been compared with the tensile data in an attempt to establish a possible correlation of the compressive, bearing, and shear characteristics with the tensile properties of the individual materials at elevated temperatures.

The test specimens, equipment, and procedures are described briefly. Test results in the form of curves illustrate the effect of temperature and exposure time on the physical properties of the various materials investigated.

Although considerable data are reported in the literature on the tensile properties of aluminum and magnesium alloys and titanium at elevated temperatures, only limited information is available on the compressive, bearing, and shear properties of these materials at higher temperatures. Therefore, a program was established at the Armour Research Foundation under Air Materiel Command Contract No. AF33(038)8681 to obtain such information for aircraft design purposes and to investigate a possible correlation of these properties with the elevated temperature tension test results.

The physical properties of aluminum and magnesium alloys are known to be markedly affected when these alloys are exposed to elevated temperatures. These effects are mainly of two types: (1) those caused by temperature alone, independent or precipitation (aging); and (2) those resulting from structural alteration of the material, dependent upon time of exposure as well as the magnitude of temperature. Consequently, time and temperature were the two primary variables considered in the study of these materials at elevated temperatures.

This paper briefly describes the program in which the tension, compression, bearing, and shear tests were performed at elevated temperatures and summarizes the results obtained on two aluminum and two magnesium alloys at temperatures between 212 F and 700 F with exposure periods ranging from 0.5 to 1000 hr, and on annealed and cold rolled titanium at temperatures between 400 F and 1000 F for exposure periods of 0.5 to 100 hr. Room temperature tests served as a basis for comparison of the elevated temperature results.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Kaiser Aluminum and Chemical Sales, Inc., Chicago Ill.

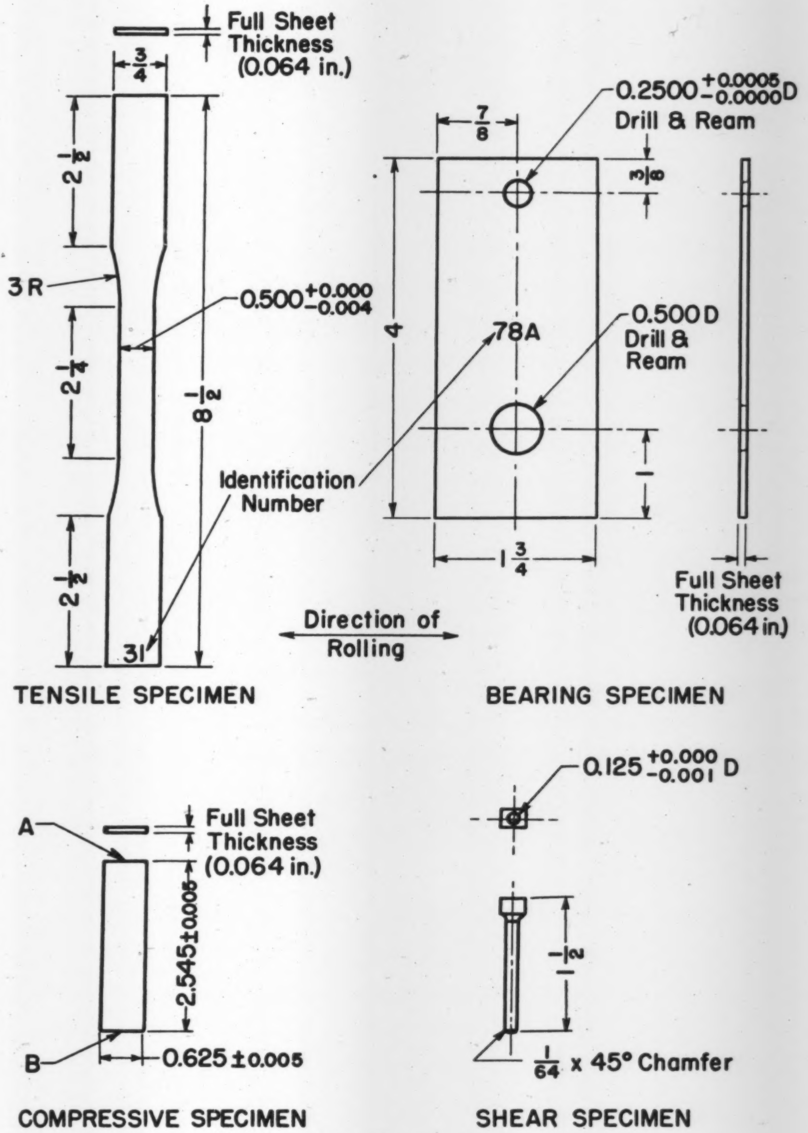
Full Sheet Thickness (0.064 in.)
3/4
2 1/2
3 R
0.500 +0.000 −0.004
2 1/4
8 1/2
Identification Number
2 1/2
31
TENSILE SPECIMEN
0.2500 +0.0005 −0.0000 D
Drill & Ream
7/8
3/8
4
78A
0.500 D
Drill & Ream
1
1 3/4
Full Sheet Thickness (0.064 in.)
Direction of Rolling
BEARING SPECIMEN
A
Full Sheet Thickness (0.064 in.)
2.545±0.005
B
0.625±0.005
COMPRESSIVE SPECIMEN
0.125 +0.000 −0.001 D
1 1/2
1/64 x 45° Chamfer
SHEAR SPECIMEN

FIG. 1.—Test Specimens.

The investigation was conducted on

sheet materials of 24S-T3 and 75S-T6 aluminum alloy (clad), FS-1h and MH magnesium alloy, and annealed and cold-rolled commercially pure titanium. For the tension, compression, and bearing tests, the sheets were 0.064 in. thick, while the materials for the shear and corresponding tension tests were approximately $\frac{3}{16}$ in. thick. To obtain the minimum properties, the specimens were stressed in the cross-grain direction.

The following properties of the six materials were determined at various temperatures and exposure periods:

1. Compressive yield stress (0.2 per cent offset).
2. Modulus of elasticity in compression.
3. Bearing yield stress (0.2 per cent offset).
4. Ultimate bearing stress.
5. Ultimate shear stress.
6. Tensile yield stress (0.2 per cent offset).
7. Modulus of elasticity in tension.
8. Ultimate tensile stress.

PREPARATION AND PRELIMINARY AGING OF TEST SPECIMENS

Blanks were band-sawed from the sheets in such a manner that all speciments would be stressed in the cross-grain direction under the application of load; before aging, an identification number was scribed on one face of each. Except for the $\frac{1}{2}$-hr specimens, which were aged in the test fixture at the time of testing, all blanks were aged before being machined to finished dimensions. Temperature variations throughout the aging cycle were observed to be no greater than ±5 F.

After removal from the preheat ovens, the finished specimens were machined to conform to the dimensions shown in Fig. 1. All specimens were polished with No. 00 emery paper to remove burrs and small irregularities.

SPECIAL TEST EQUIPMENT

The apparatus for each of the four types of tests consisted of three parts: a fixture for applying load to the specimens, a deformometer for measuring strains, and a furnace for heating the fixture and specimens. Generally, it was necessary to construct specialized fixtures for the various tests.

Tension Test Apparatus:

The tensile loading fixture consisted of a pair of standard self-aligning tensile grips suspended from the crosshead of a universal testing machine. The extensometer consisted of two rigid Y-shaped yokes connected at their mid-points by an eye-bolt assembly which permitted the lower yoke to pivot with respect to the top (see Fig. 2). The open end of each frame was attached to the specimen by means of two conically pointed screws seated in gage marks located on opposite edges. At the opposite end of the frame, a tube was fastened to the top yoke, and a concentric rod was passed through this tube to contact a spherical surface on the lower yoke. The top of the rod extended approximately $1\frac{1}{2}$ in. above the outside tube. The relative motion between the tube and rod caused by deformation of the test specimen was measured by a Tuckerman optical strain gage mounted on the end of the tube. The lozenge of the gage firmly contacted a collar through which the rod passed. The collar was held in position on the rod by a spring and thumb nut. After the gage had traveled through its range, it was reset by turning the thumb screw which moved the collar down the rod and rotated the lozenge. In this manner it was possible to reset the gage as many times as necessary without removing the lozenge from the collar. Since the lever ratio of the extensometer frame was unity, the change in the Tuckerman readings was directly proportional to the average value of the changes in length defined by sets of gage marks located on opposite edges of the specimen.

Compression Test Apparatus:

The design of the compressive fixture is similar to the loading fixture developed by Dorn.[2] It consisted of a base with a steel insert, two hardened steel guide blocks, and a guided loading ram. The steel insert, hardened and ground, provided a flat polished support for the specimen, while the two guide blocks restricted lateral buckling of the specimen during loading. One guide was bolted to the rigid uprights of the fixture, while the other was free to move. The clearance between the specimen and guides was controlled by two thumb screws forcing against the back of the movable block. The hardened steel loading plunger was located in the upper portion of the test fixture and was guided with its polished bearing surface parallel to that of the insert in the base. Loads were applied to the hemispherical surface at the upper extremity of the plunger by the plane end of a ram attached to the crosshead of the testing machine. Before inserting each specimen in the fixture, the faces of the specimens were coated with Molykote dry lubricant to reduce friction between the specimen and guide blocks.

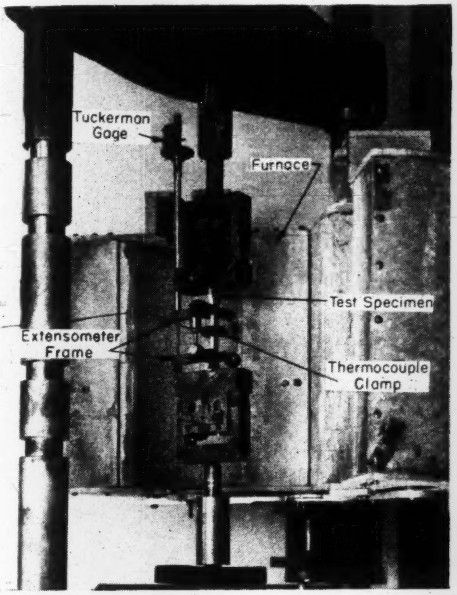

FIG. 2.—Tension Test Apparatus Showing Extensometer, Control Thermocouple, and Furnace.

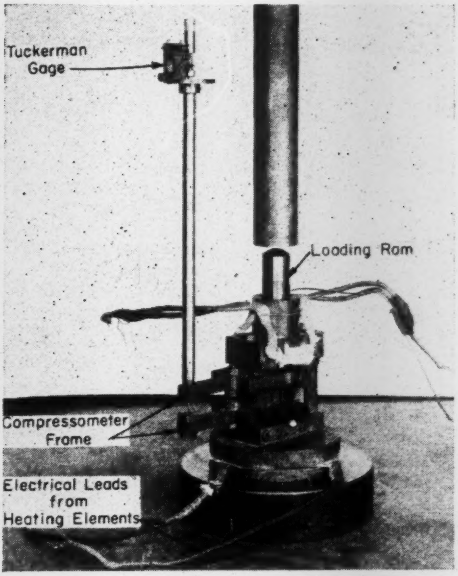

FIG. 3.—Compression Test Fixture with Compressometer Mounted on a Test Specimen.

The compressometer, shown in Fig. 3, is identical to that used for the tension tests, except that the upper and lower compressometer frames were connected with an elastic hinge located midway between the gage points and the concentric tube and measuring rod, instead of with a rigid eye-bold assembly. The deformations were measured by a Tuckerman optical strain gage mounted on the concentric rod and tube in the manner described for the tension test equipment.

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[2] A. E. Flanigan, L. F. Tedsen, and J. E. Dorn, "Compressive Properties of Aluminum Alloy Sheet at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, pp. 954–955 (1946).

Bearing Test Apparatus:

The bearing test fixture was constructed in accordance with Fig. SM-19T of NDRC Report No. M-566.[3] Figure 4 shows the bearing test fixture, specimen, and deformometer. The loading fixture consisted essentially of a set of double shear jigs built of hardened and ground steel plates. The specimen was held in the fixture by hardened shear pins passing through the reamed holes of the side plates and specimen. Upon the application of load, the bearing stresses and deformations occurred at the 0.250-in. dowel pin.

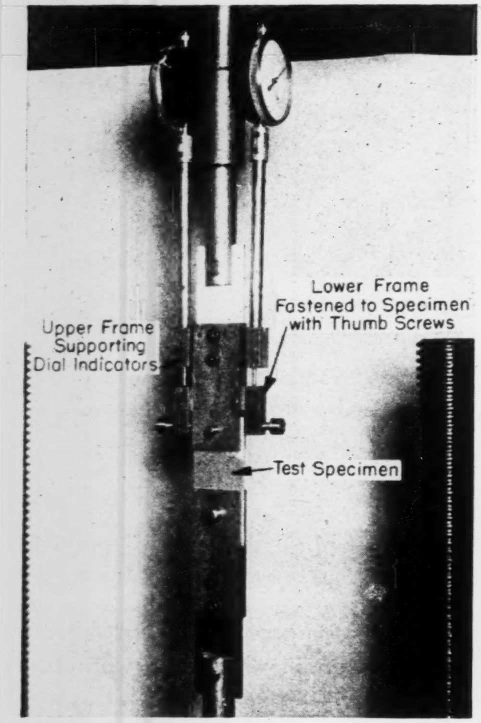
Upper Frame Supporting Dial Indicators
Lower Frame Fastened to Specimen with Thumb Screws
Test Specimen

FIG. 4.—Bearing Test Fixture with Deformometer Attached to Specimen.

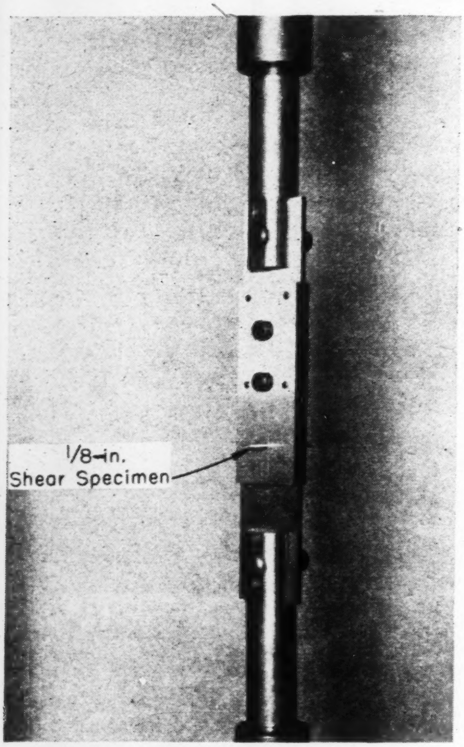

FIG. 5.—Shear Test Fixture.

The deformometer used for measuring bearing deformation consisted of a frame to hold the dial indicators and a reference clamp to fasten on the test specimen. The upper frame was bolted to the test fixture and represented the motion of the $\frac{1}{4}$-in. hardened steel dowel pin passing through a reamed hole in the specimen. Two pieces of steel tubing, which were threaded into this upper frame symmetrically with the axis of load application, supported two dial indicators with shafts which extended through these tubes and contacted the lower section of the extensometer frame. This lower frame was fastened to the edges of the test specimen in line with the edge of the reamed hole. Thus, the motion between the test specimen and the dowel pin, which represented the bearing deformation of the reamed hole, was obtained by averaging the two dial indicator readings.

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[3] "Test Methods of the Materials Laboratory," Engineering Division, Air Technical Service Command, *NDRC Report No. M-566*, Vols. I and II (1945).

Shear Test Apparatus:

The shear fixture, which complies with Fig. SM-17T,[3] is shown with a shear specimen in place in Fig. 5. This fixture consisted of two side plates fastened to a center spacer plate and a shear tool of hardened steel. The specimen was inserted through the 0.125-in. diameter holes of the supporting fixture and the shear tool and was loaded in double shear. Since only the ultimate shear stresses were determined during these tests, no deformation measuring devices were required.

TABLE I.—PHYSICAL PROPERTIES OF VARIOUS NON-FERROUS STRUCTURAL MATERIALS AT ROOM TEMPERATURE.

Properties	Aluminum Alloy		Magnesium Alloy		Titanium	
	24S-T3	75S-T6	FS-1h	MH	Annealed	Cold-Rolled
Tension test of 0.64-in. flat sheet						
Yield strength, 2 per cent offset, psi	43 100	63 200	63 200	25 000	62 600	90 300
Tensile strength, psi	62 300	72 200	41 200	34 500	76 200	102 700
Modulus of elasticity, psi	11.0×10^6	10.2×10^6	6.6×10^6	6.1×10^6	16.3×10^6	16.4×10^6
Compression test of 0.064-in. flat sheet						
Yield strength, 0.2 per cent offset, psi	48 700	70 750	25 560	17 900	57 400	88 500
Modulus of elasticity, psi	10.9×10^6	10.8×10^6	6.9×10^6	6.2×10^6	16.8×10^6	15.8×10^6
Bearing test of 0.064-in. flat sheet						
Yield strength 2 per cent of hole diameter, psi	70 150	93 200	46 200	32 200	94 200	129 000
Ultimate strength, psi	102 600	116 900	58 000	51 400	134 300	146 000
Shear test on 1/8-in. rounds						
Ultimate strength, psi	41 100	47 300	21 100	15 600	54 700	57 400
Tension test of 3/16-in. plate						
Tensile strength, psi	63 400	76 600	43 500	31 600	76 000	105 200

TEST PROCEDURE

For all tension, compression, bearing, and shear tests, the temperatures were measured and controlled by a chromel-alumel thermocouple and a Micromax recording controller, respectively. During the tension, bearing, and shear tests, the temperature of the specimen and fixture was maintained in a standard cylindrical furnace having a test chamber 12 in. long and 5 in. in diameter.

The compression specimens and test fixture were heated to test temperature by means of four cartridge heaters, inserted into holes drilled longitudinally through the guide blocks, and a flat-plate heating element built into the base of the test fixture. The voltages supplied to the cartridge heaters and the plate element located in the base were controlled separately. The entire assembly was placed in an insulated container to reduce heat losses. Openings were cut in the Transite cover plate to permit passage of the loading ram and extensometer tube. With this method of heating, it was possible to increase the temperature of the specimen and test fixture from 75 F to 700 F in approximately 10 min, with even less time required for the lower temperatures.

Before each type of test was conducted, a survey was made of the temperature distribution throughout a dummy test specimen mounted in the corresponding fixture and heated in the test furnace. These elevated temperature checks were made in accordance with standard procedures outlined in ASTM method E 21–43.[4]

Standard procedures were followed in

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[4] Recommended Practice for Short-Time Elevated-Temperature Tension Tests of Metallic Materials (E 21–43), 1949 Book of ASTM Standards, Part 1, p. 1274.

conducting each of the four types of tests. Stress-strain data were obtained from tension, compression, and bearing tests.

A minimum of two specimens was tested under each condition in order to check the reliability of the empirical results. Three or more specimens were tested where discrepancies occurred. Shear tests were conducted in accordance with the procedures outlined by National Defense Research Committee.[5]

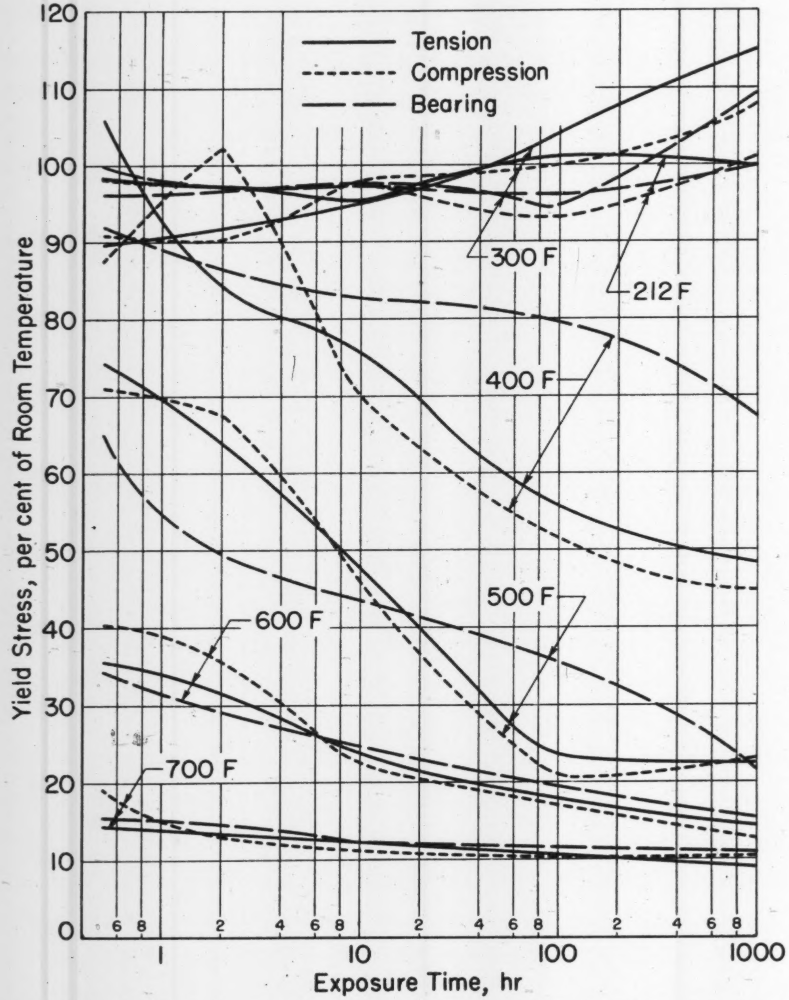

FIG. 6.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of 24S-T3 Aluminum Alloy.

SUMMARY OF TEST RESULTS

The effects of temperature and time on the physical properties of non-ferrous structural materials are chiefly of two types: (1) changes which are caused by the effect of temperature alone, and (2) changes which result from structural alterations of the material and which depend upon exposure time as well as temperature. In agreement with discussions by Dorn,[6] it is believed that for tests of specimens exposed to the various temperatures for ½ hr, the physical properties are affected chiefly by temperature, whereas changes in physical properties observed in tests of specimens subjected to longer exposure periods are caused by exposure time as well as temperature. The effect of these two variables (temperature and time) is discussed separately.

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[5] "Test Methods of the Materials Laboratory," Engineering Division, Air Technical Service Command, *NDRC Report No. M-566*, Vol. I, p. 10 (1945).

The physical properties of the six ma-

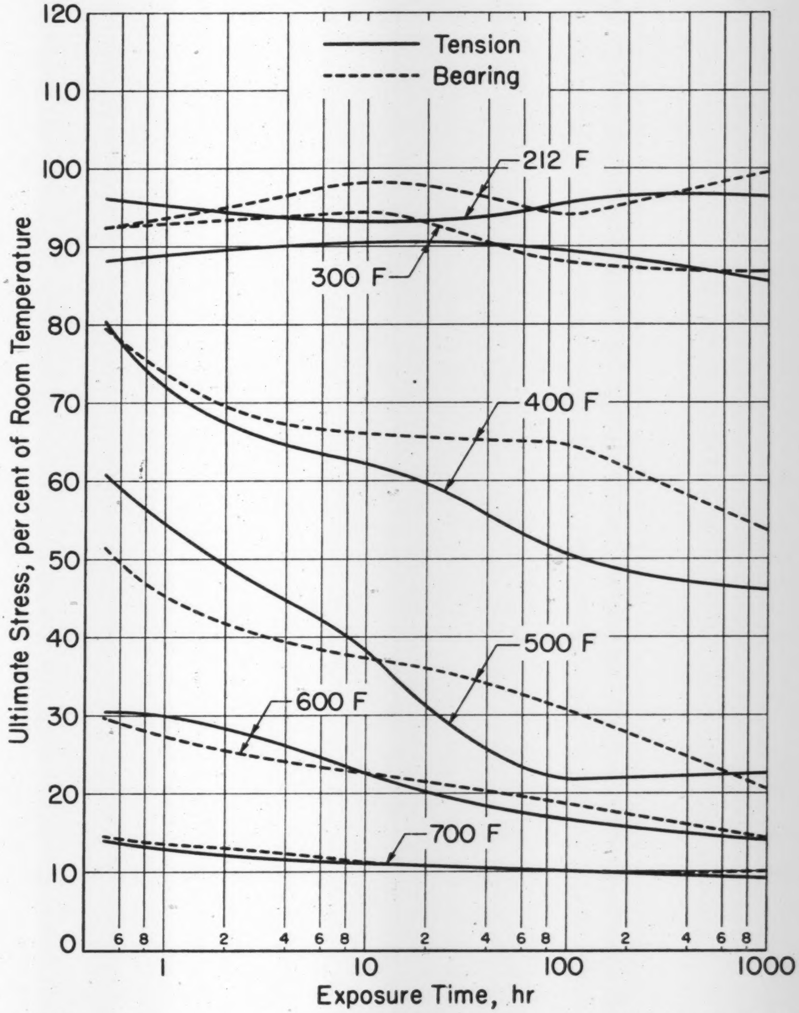

FIG. 7.—Effect of Temperature and Exposure Time on the Tensile and Bearing Stresses of 24S-T3 Aluminum Alloy.

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[6] A. E. Flanigan, L. F. Tedsen, and J. E. Dorn, "Compressive Properties of Aluminum Alloy Sheet at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 963 (1946).

terials investigated have been expressed as percentages of the corresponding room temperature values. These room temperature values are presented in Table I. It should be noted that for any given material, the Ultimate tensile strengths were not the same for specimens obtained from 0.064 in. and $\frac{3}{16}$ in. thick sheets. Consequently, a direct comparison of ultimate bearing and ultimate shear stresses should not be made since these tests were performed on specimens cut from sheets of different thicknesses. For the two aluminum and two magnesium alloys, the physical properties have been plotted against exposure time, and curves have been drawn to illustrate the percentage change in properties resulting

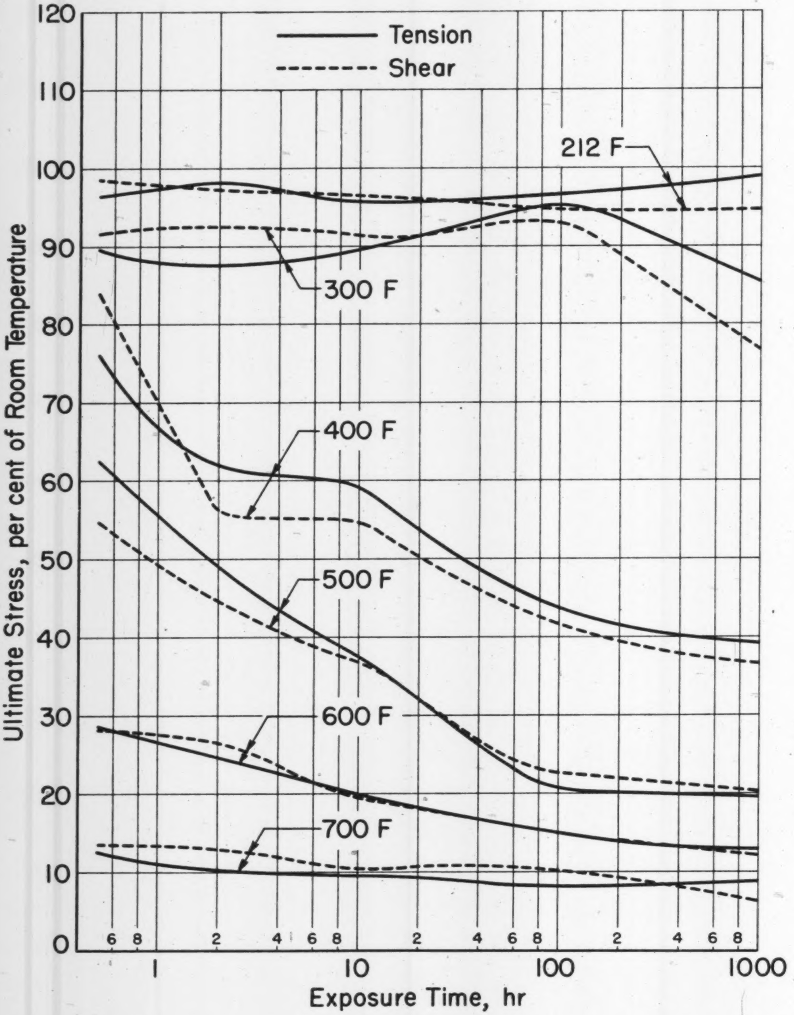

FIG. 8.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of 24S-T3 Aluminum Alloy.

from temperature and time to aid in comparing the effects of these two variables on the corresponding physical property value.

Since the titanium materials were investigated at only two exposure periods, curves have been drawn to illustrate the effect of temperature on the physical properties (expressed in terms of room temperature values) for ½- and 100-hr exposure periods.

decrease steadily with increase in time, except for the compressive yield stress at 400 F which was observed to increase at 2 hr over the ½-hr value. Exposure time seems to have its greatest effect on these properties at 500 F. The greatest decrease in these percentages resulting from temperature alone (½-hr exposure time) occurred between 500 and 700 F.

Curves illustrating the effect of temperature and time on the ultimate tensile and bearing stresses for 0.064 in. thick 24S-T3 aluminum alloy sheet are presented in Fig. 7, while the ultimate tensile and shear stresses of specimens cut from $\frac{3}{16}$-in. sheet are shown in Fig. 8.

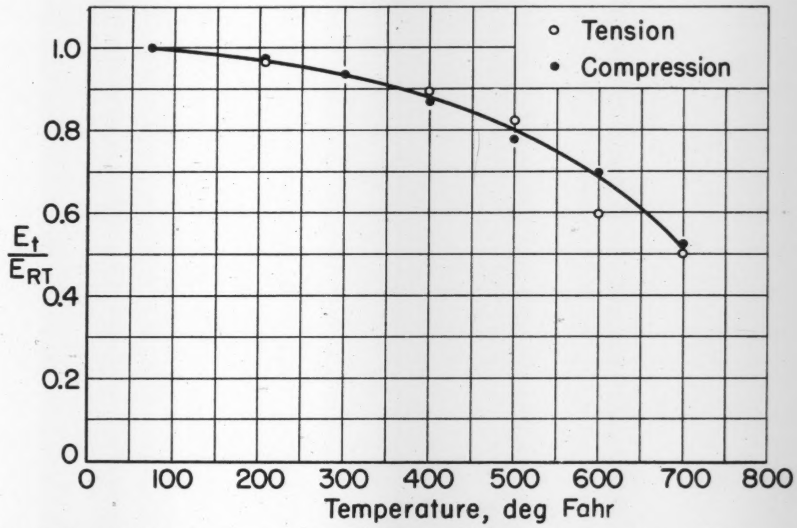

FIG. 9.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of 24S-T3 Aluminum Alloy.

Effect of Temperature and Exposure Time on 24S-T3 Aluminum Alloy:

Figure 6 shows the effect of temperature and time on tensile, compressive, and bearing yield stresses at various temperatures for 24S-T3 aluminum. In general, the yield stresses respond similarly to temperature and time, as shown by the corresponding curves. For temperatures of 212 F and 300 F, these properties seem to be essentially independent of exposure times ranging from ½ to 100 hr; however, a 1000-hr exposure period tends to increase the yield stress above its room temperature value. At temperatures between 400 and 700 F, the yield stresses

In Fig. 9, which shows the effects of temperature on modulus of elasticity in tension and compression, the ratio of the mean value of modulus of elasticity for each temperature was plotted for the corresponding temperatures. It is shown that the points for modulus of elasticity in both tension and compression describe the same curve, indicating that close correlation exists between the ratio E_{t_1}/E_{RT} for tension and compression. The curve shown that the decrease in the E_t/E_{RT} ratio is progressively greater as the temperature is increased from 78 F to 700 F.

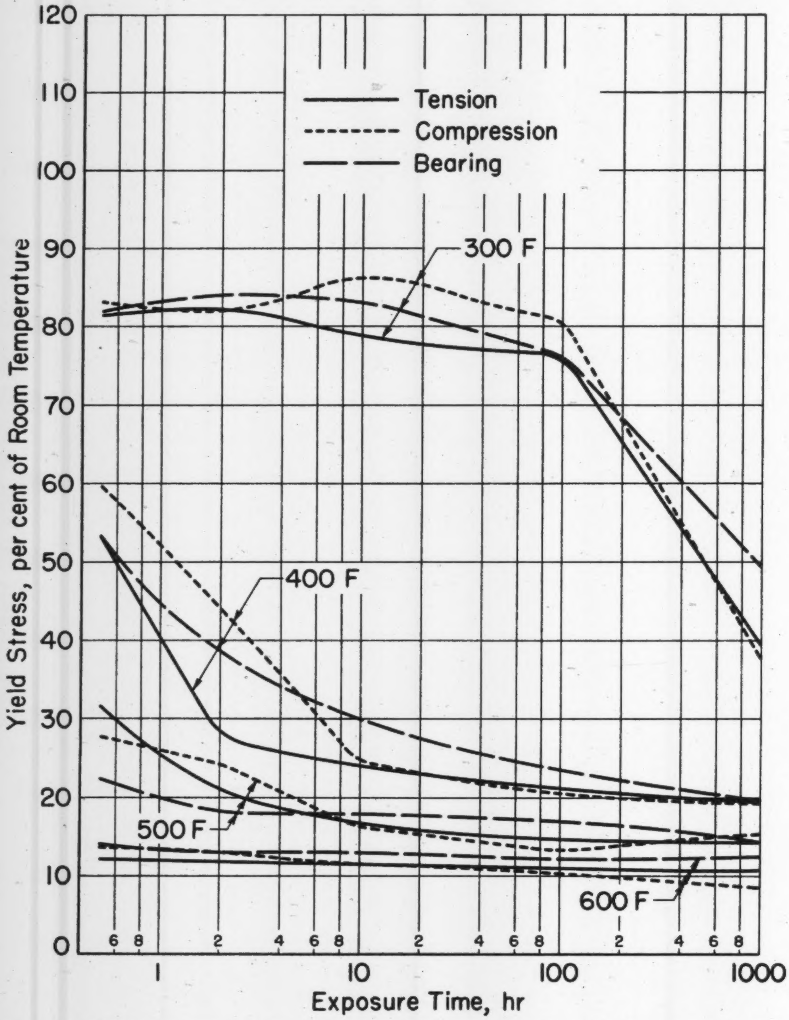

FIG. 10.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of 75S-T6 Aluminum Alloy.

Effect of Temperature and Exposure Time on 75S-T6 Aluminum Alloy:

The physical properties of 75S-T6 aluminum alloy at elevated temperatures and exposure times, expressed as a percentage of corresponding room temperature values, are compared in Figs. 10 through 13. In Fig. 10, the corresponding tensile, compressive, and bearing yield stress curves are similar in shape, indicating that these yield properties are affected similarly by the time of exposure.

The ultimate tensile and bearing stress curves in Fig. 11 and the ultimate tensile and shear stress curves for $\frac{3}{16}$-in. material in Fig. 12 exhibit changes resulting from temperature and time similar to those which occurred in the yield stress properties.

The ratios of mean values of modulus of elasticity in tension and compression to the corresponding modulus of elasticity at room temperature were calculated for each temperature. These ratios (E_{t_1}/E_{RT}) were plotted for the various temperatures in Fig. 13, and curves were drawn to illustrate the effect of temperature on the ratio.

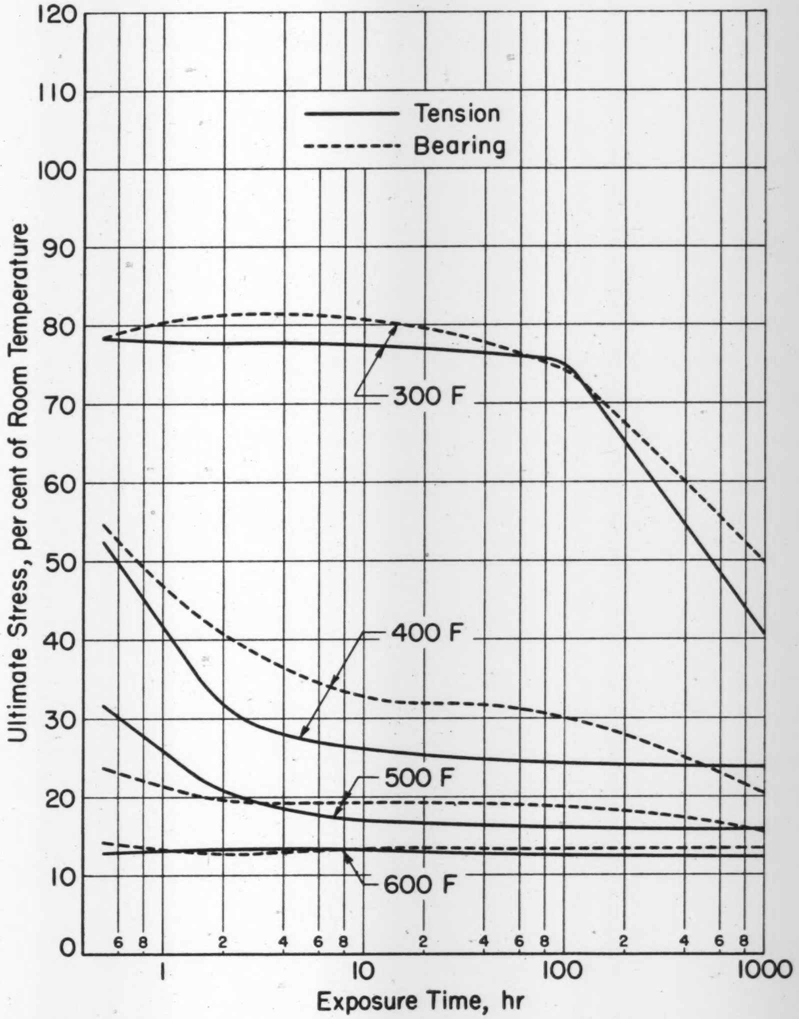

FIG. 11.—Effect of Temperature and Exposure Time on the Tensile and Bearing Stresses of 75S-T6 Aluminum Alloy.

Above 300 F, temperature exerts a more pronounced effect on the yield properties of 75S-T6 aluminum alloy than on those of the 24S-T3 alloy. In fact, the yield strength of 24S-T3, while lower at room temperature, is appreciably higher than 75S-T6 at temperatures above 300 F. Below 300 F, precipitation hardening largely offsets the decrease in yield and ultimate strength, which would be expected to result from exposure to elevated temperatures, for both 24S-T3 and 75S-T6 aluminum. This effect is more pronounced in 24S-T3.

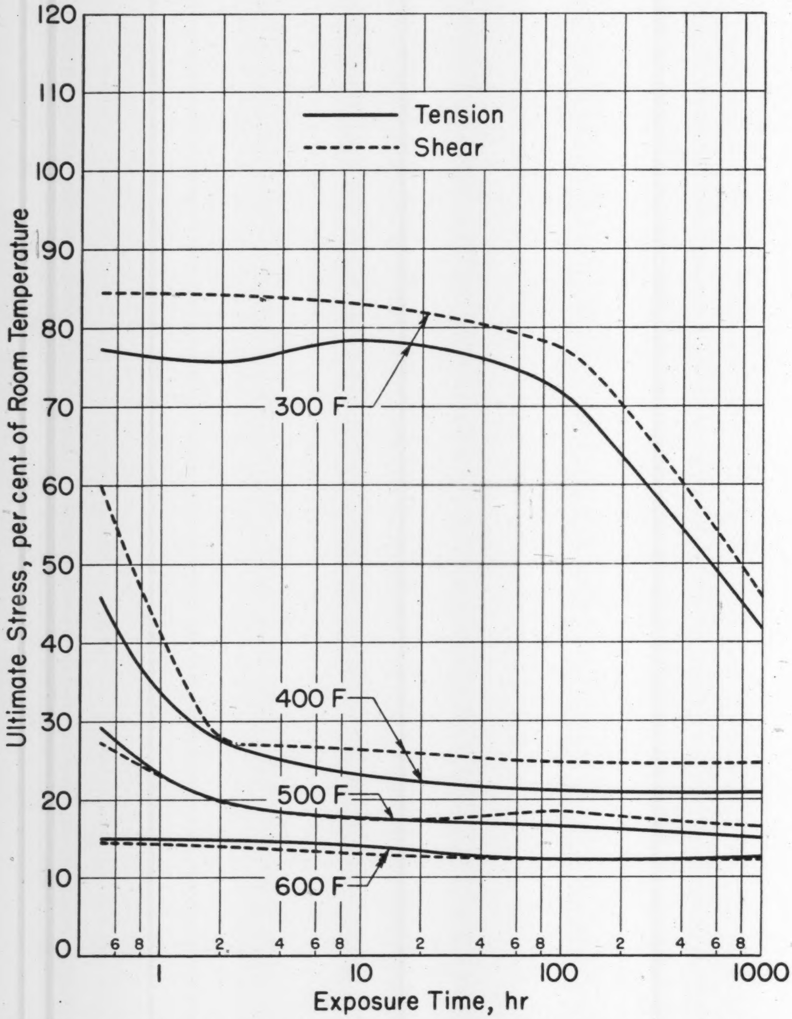

FIG. 12.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of 75S-T6 Aluminum Alloy.

Effect of Temperature and Exposure Time on FS-1h Magnesium Alloy:

The properties of FS-1h magnesium alloy were summarized by curves in Figs. 14 through 17 to aid in comparing the effects of temperature and time on (1) the tensile, compressive, and bearing yield stresses, (2) ultimate tensile and bearing stresses, (3) ultimate tensile and shear stresses ($\frac{3}{16}$-in. sheet), and (4) modulus of elasticity in tension and compression. From these curves, it is seen that exposure time exhibits a negligible effect on the physical properties of this material. However, elevated temperatures affect the yield and ultimate properties, as shown by the percentage value curves in Figs. 14, 15, and 16. The greatest reduction was observed for temperature changes from 78 F to 300 F and from 300 F to 400 F.

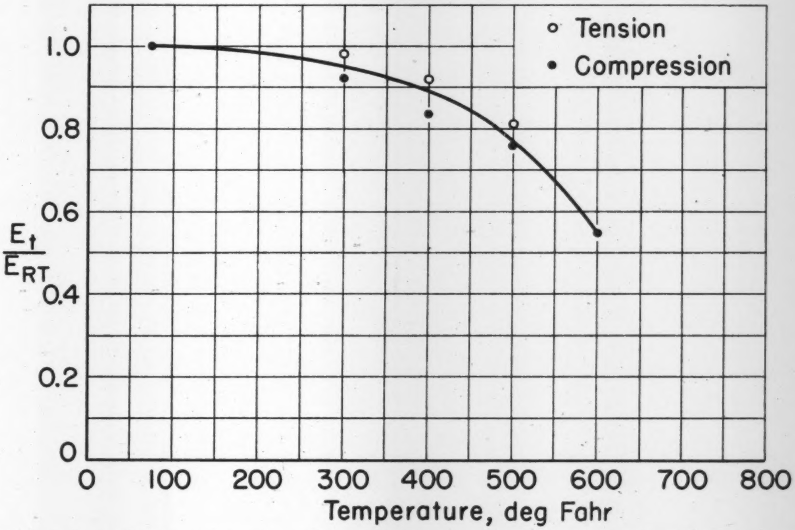

FIG. 13.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of 75S-T6 Aluminum Alloy.

Effect of Temperature and Exposure Time on MH Magnesium Alloy:

The various physical properties of MH magnesium alloy have been expressed in terms of corresponding room temperature values by curves in Figs. 18 through 21. Except in a few cases, as shown by the individual curves, exposure time has negligible effects on the physical properties.

Effect of Temperature and Exposure Time on Annealed Titanium:

The tensile, compressive, and bearing yield stresses of annealed titanium *versus* temperature curves for $\frac{1}{2}$- and 100-hr exposure times have been presented in Fig. 22 for comparison purposes; Fig. 23 illustrates the effect of temperature and time on the ultimate tensile and bearing stresses. Utimate tensile and shear stresses *versus* exposure time curves are shown in Fig. 24. The small deviation between the curves for $\frac{1}{2}$- and 100-hr exposure indicates that neither the yield nor the ultimate stress properties are appreciably affected by exposure time. Temperature increases, however, exert considerable influence on these properties. The variation of tensile and compressive moduli of elasticity with temperature is summarized in Fig. 25. These moduli are expressed in terms of room temperature, and the ratio is plotted for the various temperatures.

Effect of Temperature and Exposure Time on Cold-Rolled Titanium:

Figures 26 through 29 illustrate the effect of temperature and time on the physical properties of cold-rolled titanium at elevated temperatures. The ex-

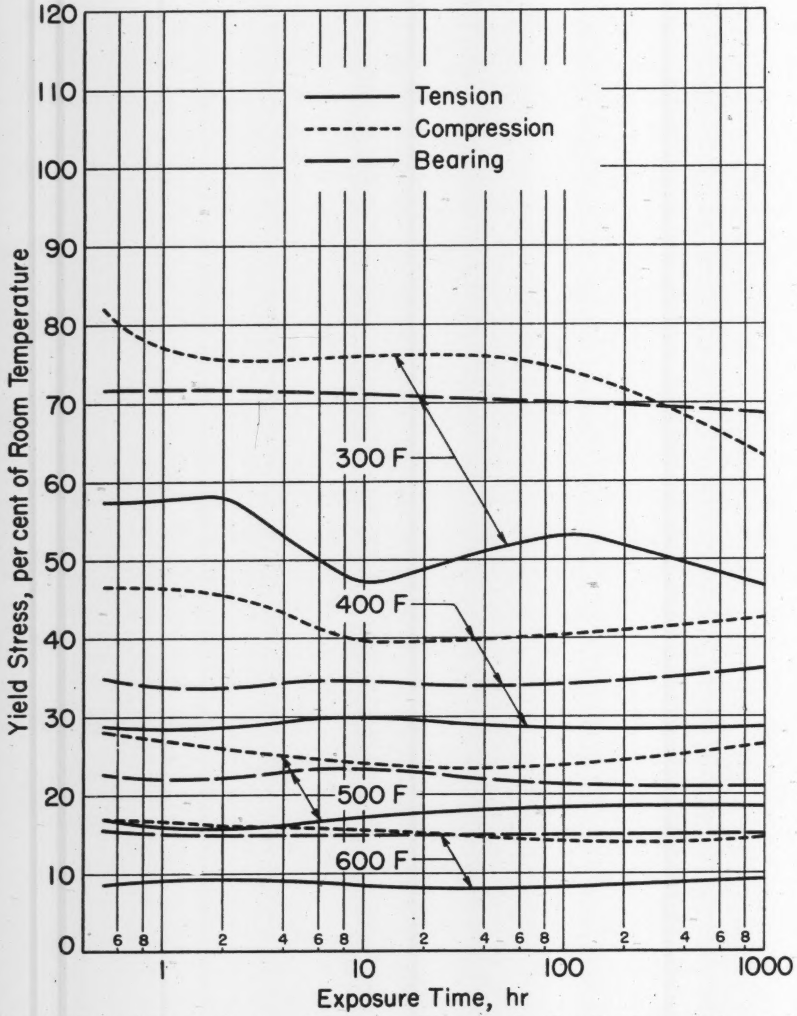

FIG. 14.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of FS-1h Magnesium Alloy.

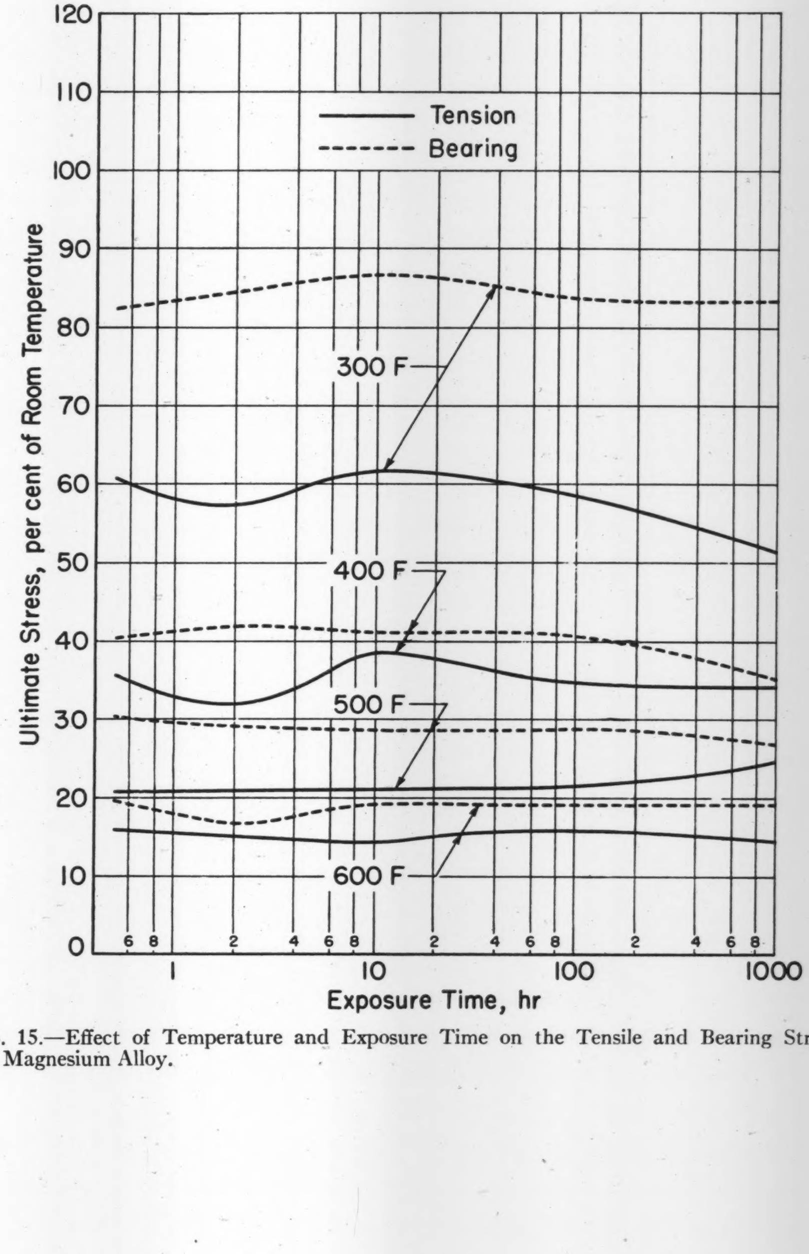

FIG. 15.—Effect of Temperature and Exposure Time on the Tensile and Bearing Stresses of FS-1h Magnesium Alloy.

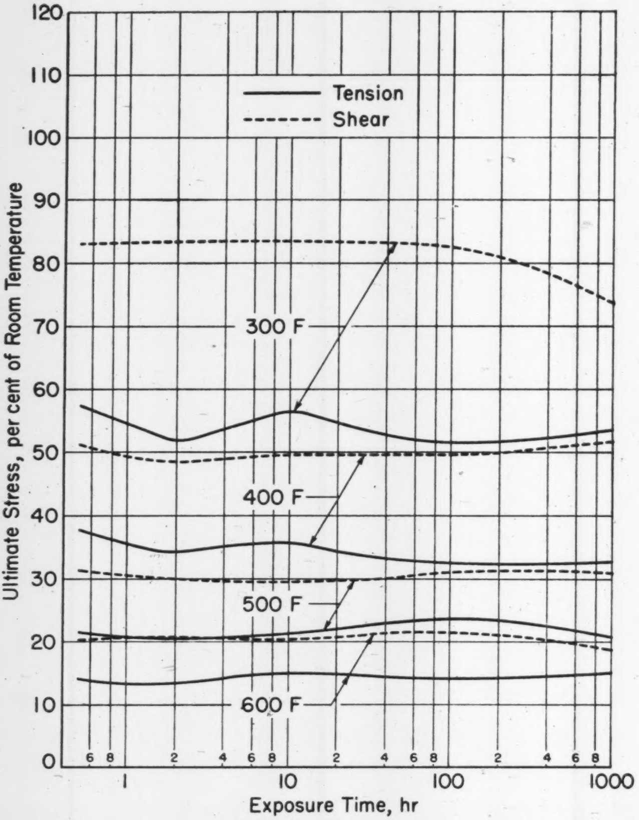

FIG. 16.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of FS-1h Magnesium Alloy.

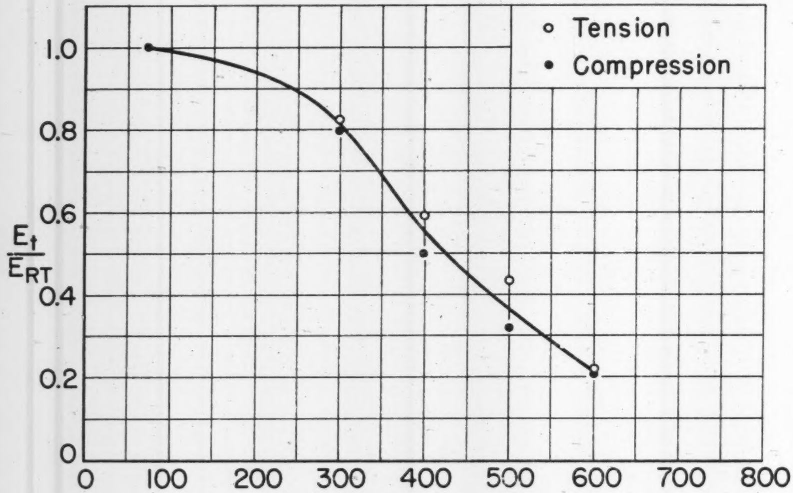

FIG. 17.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of FS-1h Magnesium Alloy.

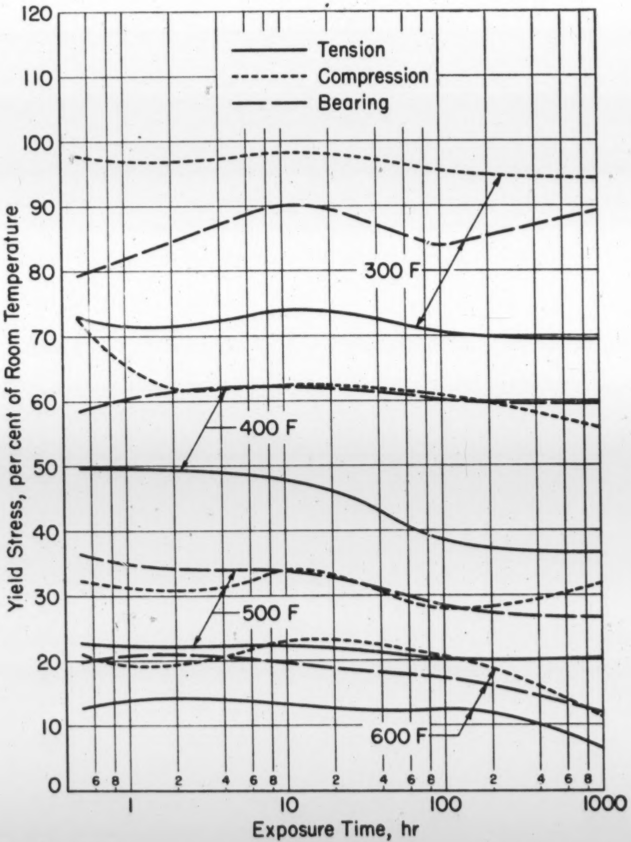

FIG. 18.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of MH Magnesium Alloy.

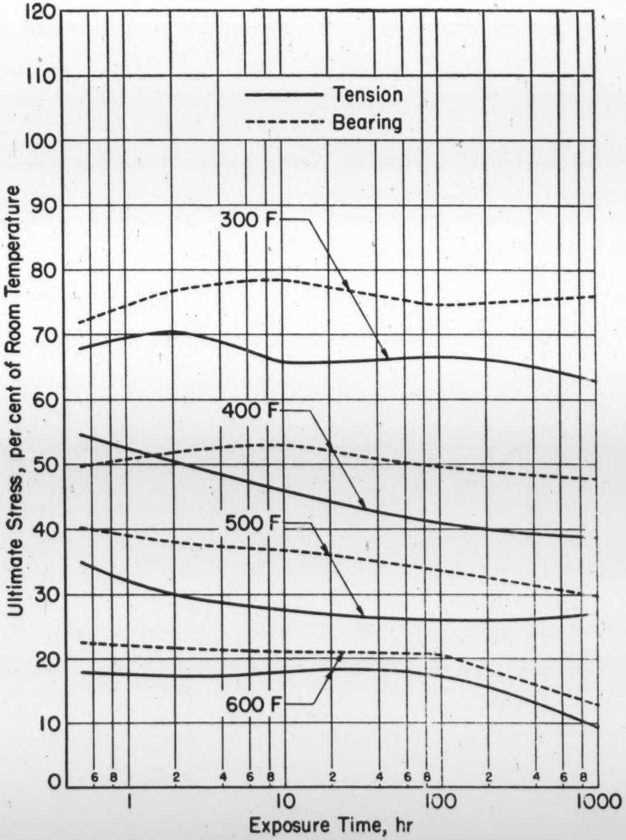

FIG. 19.—Effect of Temperature and Exposure Time on the Tensile and Bearing Stresses on MH Magnesium Alloy.

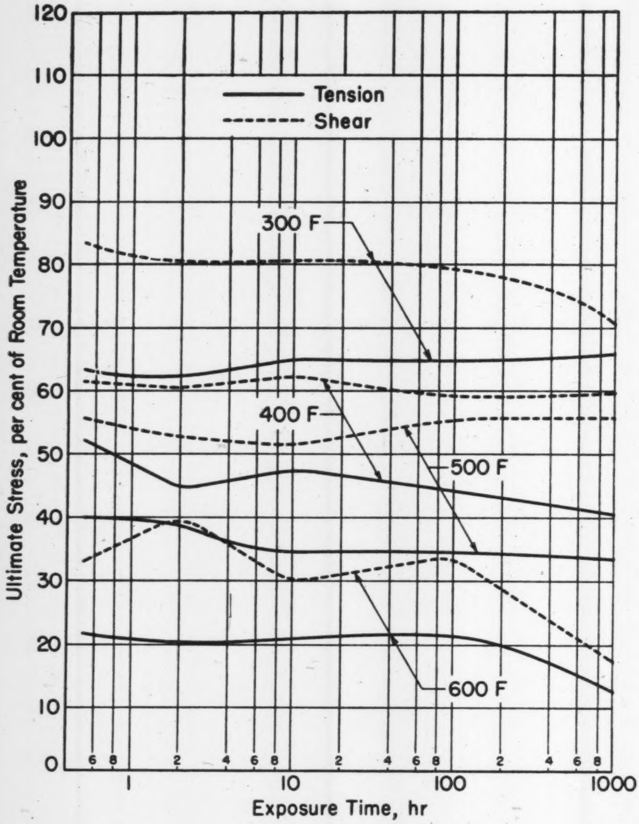

FIG. 20.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of MH Magnesium Alloy.

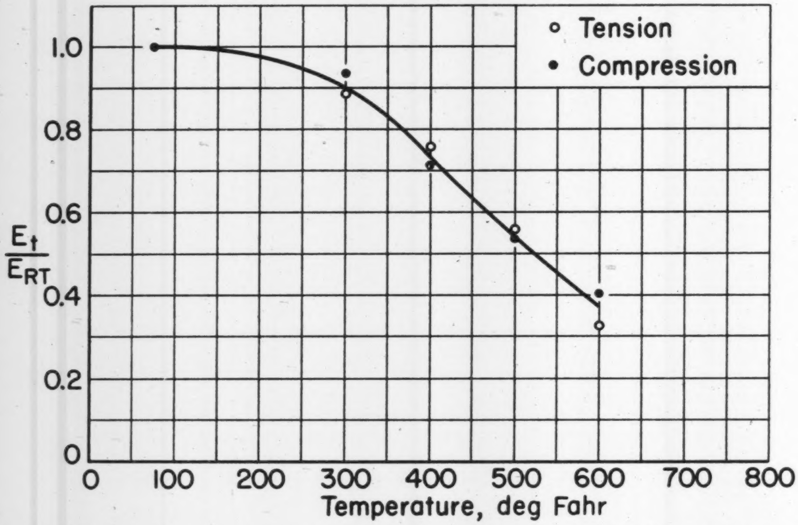

FIG. 21.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of MH Magnesium Alloy.

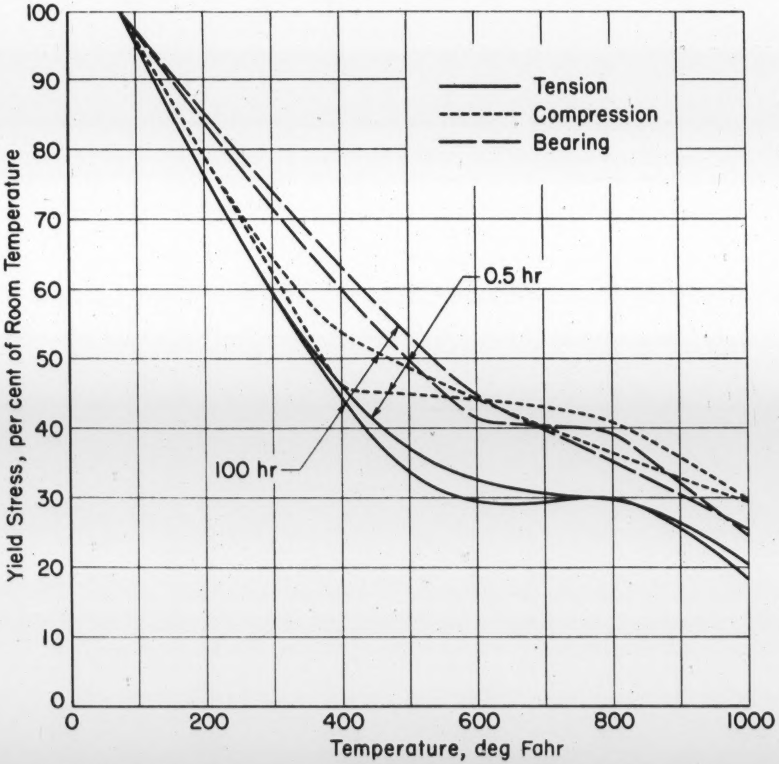

FIG. 22.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of Annealed Titanium.

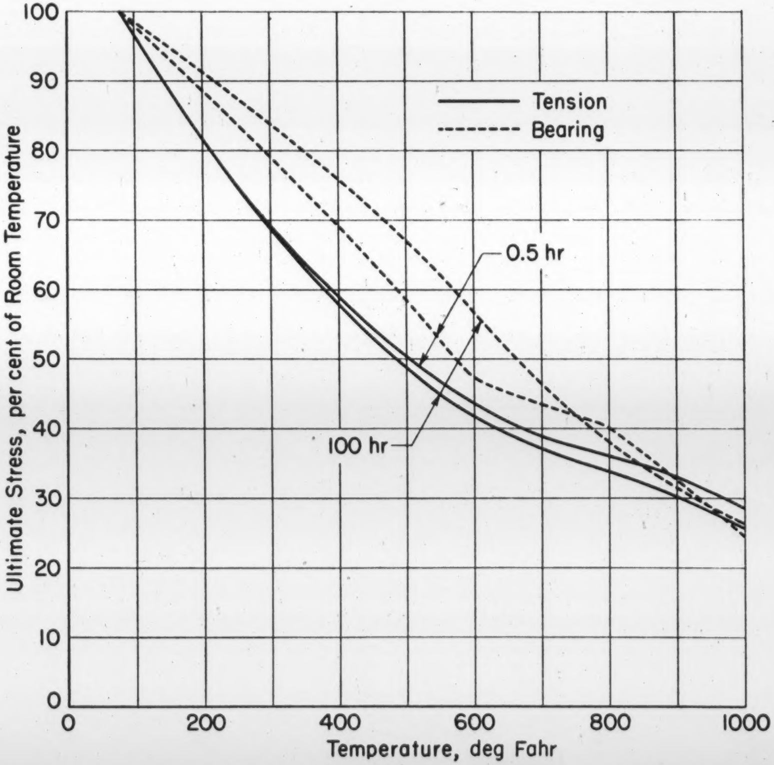

FIG. 23.—Effect of Temperatures and Exposure Time on the Tensile and Bearing Stresses of Annealed Titanium.

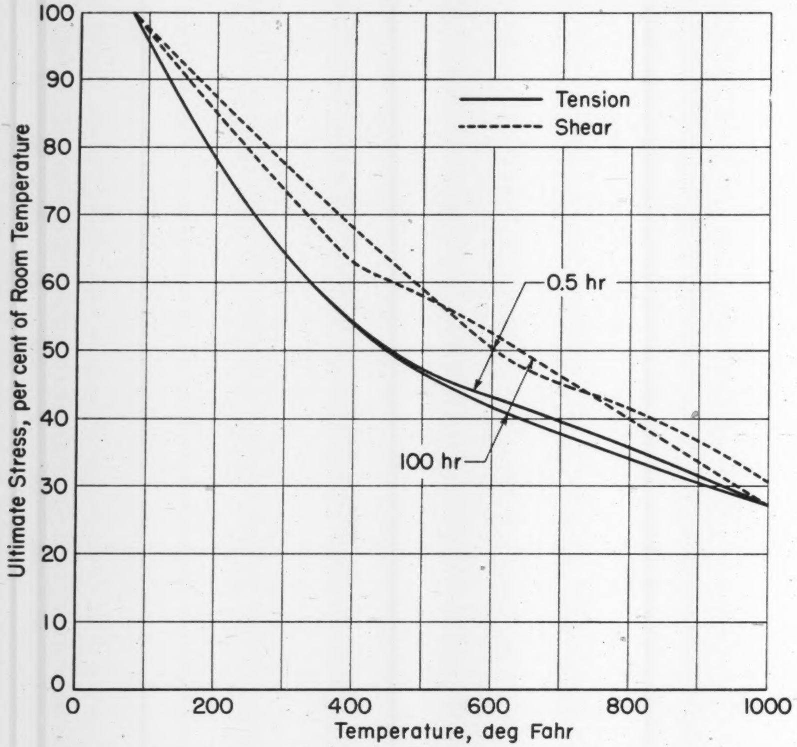

FIG. 24.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of Annealed Titanium.

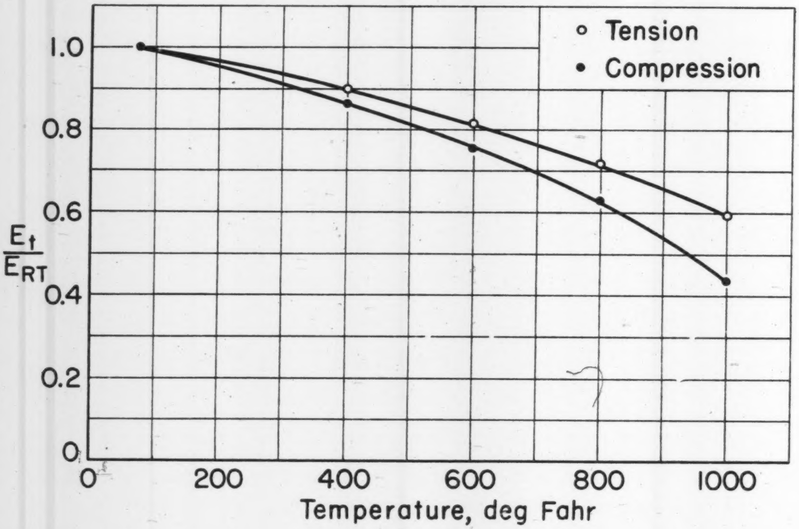

FIG. 25.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of Annealed Titanium.

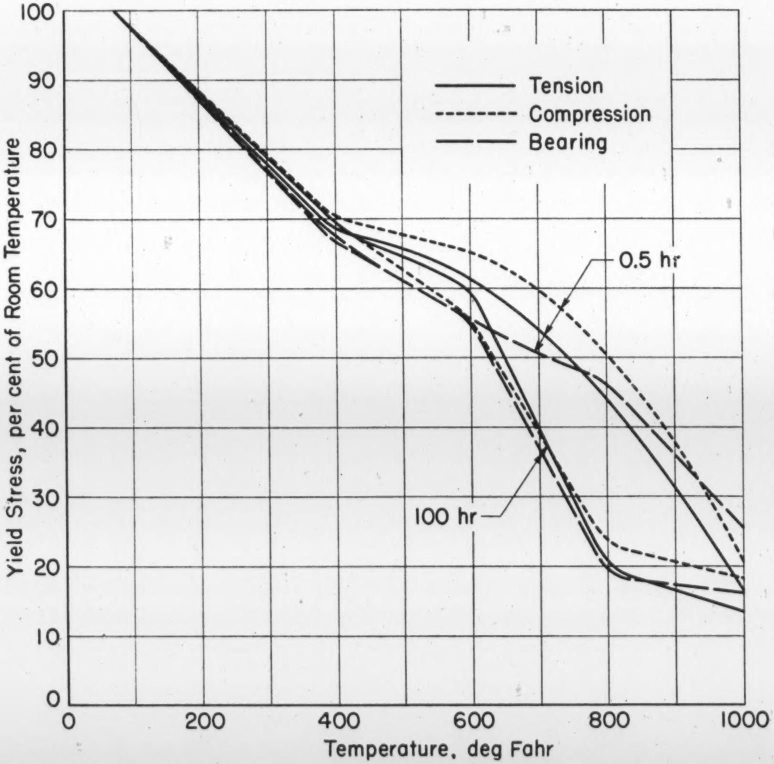

FIG. 26.—Effect of Temperature and Exposure Time on the Tensile, Compressive, and Bearing Yield Stresses of Cold-Rolled Titanium.

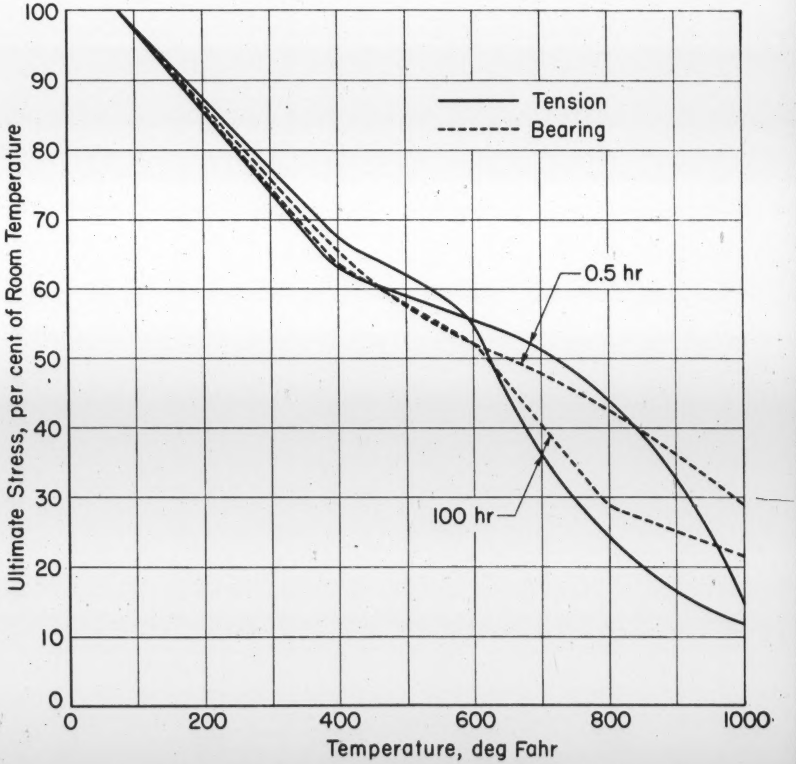

FIG. 27.—Effect of Temperature and Exposure Time on the Tensile and Bearing Stresses of Cold-Rolled Titanium.

posure time appears to have little effect on the tensile, compressive, and bearing yield stresses, and on the ultimate tensile, bearing, and shear stresses, except at 800 F. At this temperature, these properties for specimens aged for 100 hr are approximately half of the corresponding values for specimens tested after ½ hr of exposure.

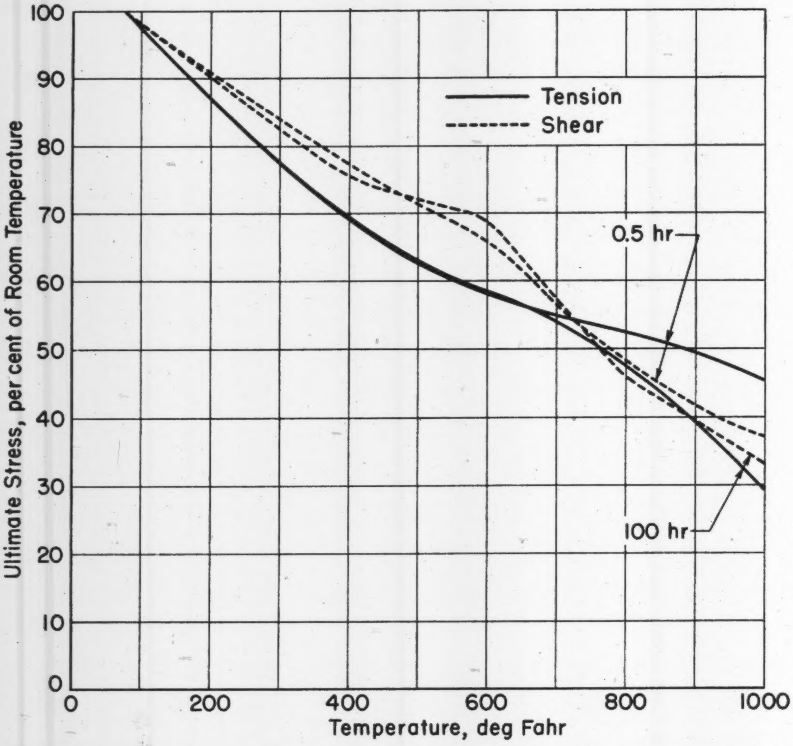

FIG. 28.—Effect of Temperature and Exposure Time on the Tensile and Shear Stresses of Cold-Rolled Titanium.

COMPARISON OF PROPERTIES AT VARIOUS TEST CONDITIONS

The effects of temperature and time on the physical properties of the various materials at elevated temperatures expressed in terms of the corresponding room temperature properties have been compared in Figs. 6 through 29. An attempt has been made to develop a means whereby the physical characteristics at a given temperature may be approximated closely by calculations based on the tension data and knowledge of the properties at room temperature.

The relationship $CYS_{t_1} = CYS_{RT}(TYS_{t_1}/TYS_{rt})$ which was used by Dorn[7, 8] for predicting compressive yield stresses at elevated temperatures, gave relatively close agreement for temperatures up to 300 F. If the physical properties may be approximated by this rela-

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[7] A. E. Flanigan, L. F. Tedsen, and J. E. Dorn, "Compressive Properties of Alluminum Alloy Sheet at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 965 (1946).

[8] A. E. Flanigan, L. F. Tedsen, and J. E. Dorn, "Bearing Properties of 24S-T Sheet and Shear Strength of 24S-T Rivets at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 38 pp. 800–804 (1947).

tionship, then

$$\frac{TYS_{t_1}}{TYS_{RT}} = \frac{CYS_{t_1}}{CYS_{RT}} = \frac{BSY_{t_1}}{BYS_{RT}};$$

$$\frac{UTS_{t_1}}{UTS_{RT}} = \frac{UBS_{t_I}}{UBS_{RT}} = \frac{USS_{t_1}}{USS_{RT}};$$

and

$$\frac{E_{(\text{tension})t_1}}{E_{(\text{tension})RT}} = \frac{E_{(\text{compression})t_1}}{E_{(\text{compression})RT}}$$

where t_I represents any desired test condition and RT is room temperature. A comparison of test results indicates that this relationship should not be used for predicting the physical characteristics for any one of the six materials investigated throughout the entire temperature ranges of this program. However, this correlation may be applicable over limited ranges. It appears that the physical properties at elevated temperatures cannot be predicted accurately by any practical method using room temperature properties. This is not unexpected, since the characteristics of stressing and mechanics of failure are dissimilar for different types of tests.

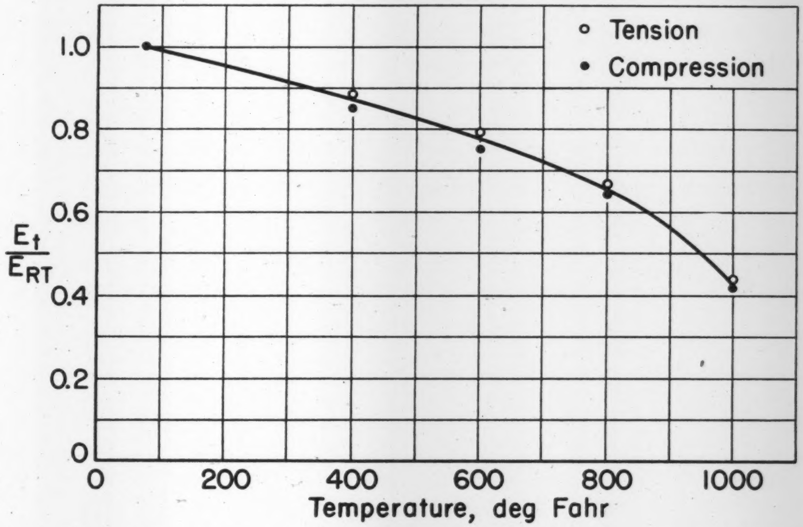

FIG. 29.—Effect of Temperature on the Modulus of Elasticity in Tension and Compression of Cold-Rolled Titanium.

SUMMARY AND CONCLUSIONS

The tensile, compressive, bearing, and shear properties of two aluminum and two magnesium alloys and two titanium materials have been determined as functions of temperature and exposure time at elevated temperatures and are presented in graphical form for design purposes. The compressive, bearing, and shear properties have been compared with the tensile data in an attempt to establish a possible means for predicting these physical characteristics at elevated temperatures from the room temperature properties and tensile data.

The following general conclusions apply to each of the six materials individually but are not applicable for comparing two different materials.

1. The tensile, compressive, and bearing yield stresses respond similarly to elevated temperature and exposure time.

These properties decrease in value with an increase in temperature.

2. The ultimate strength in tension, bearing, and shear are affected similarly by temperature and exposure time.

3. The moduli of elasticity in tension and compression decrease as the temperature is increased above room temperature, but they appear to be essentially independent of exposure time.

4. At any test temperature, the ratio E_{t_1}/E_{RT} in compression is virtually identical with this moduli ratio in tension for each material tested, except for annealed titanium.

5. Although the physical properties over limited temperature and exposure time ranges can be predicted by calculations based on the complete tension data and knowledge of the properties at room temperature, this program has illustrated that the properties over extensive temperature ranges cannot be predicted by any simple calculation.

EFFECTS OF MACHINING SPECIMENS ON THE RESULTS OF TENSION TESTS OF ANNEALED ALUMINUM ALLOYS*

By G. W. Stickley[1] and K. O. Bogardus[1]

Synopsis

The machining of specimens for mechanical tests of metals produces some cold work adjacent to the prepared surfaces. Generally its effects are insignificant and can be ignored, but in the case of annealed material the effects may be rather large. Tension tests of the annealed temper of 15 compositions of aluminum alloys described in this paper show that the yield strength of high-purity aluminum may be doubled merely by the machining of the test specimen and that some alloys having higher yield strengths are affected similarly but to a lesser extent. There is also some effect on elongation. No effect on tensile strength was found. The effects on yield strength and elongation are greater in tests of round specimens than in tests of sheet specimens.

The only way of eliminating machining effects in tests of very soft metals seems to be by testing full size, or if this is impractical, by testing specimens machined before annealing. The material, however, must contain sufficient cold work to permit a satisfactory anneal.

The preparation of the specimens used in determining the mechanical properties of metals often involves some machining, grinding, or polishing operations. Such operations may produce cold work in the metal adjacent to the prepared surfaces, and the amount and extent of this cold work depend upon the manner in which the operations are performed and upon the material. Generally the effect upon the evaluation of mechanical properties is insignificant and can be ignored but this is not necessarily true, particularly in the case of metals having low yield strengths.

Because hardness tests measure hardness at and adjacent to the surface, it has long been recognized that any effects of cold working during preparation of the surface may have a significant effect upon the results of such tests. For this reason the Tentative Method of Test for Brinell Hardness of Metallic Materials (E 10 – 50 T)[2] states that, in preparing the surface of the test specimen, "Care should be taken to avoid overheating or cold working the surface." Similarly, the Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 – 42)[3] state: "In removing surface films and other imperfections, care must be taken not to

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*Presented at the Fifty-fifth Annual Meeting of the Society June, 23-27, 1952.

[1] Assistant Chief, and Research Engineer, respectively, Mechanical Testing Div., Aluminum Research Laboratories, New Kensington, Pa.

[2] Tentative Method of Test for Brinell Hardness of Metallic Materials (E 10 – 50 T). 1950 Supplement to 1949 Book of ASTM Standards, Part 1, p. 286, Part 2, p. 197.

[3] Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 – 42), 1949 Book of ASTM Standards, Part 1, p. 1261; Part 2, p. 1025.

change the hardness of the material by cold working or undue heating."

A somewhat similar situation exists in fatigue tests employing bending stresses, because both the maximum stresses in the specimen and the maximum amount of cold work from preparation of the surface are at the same location. The ASTM Manual on Fatigue Testing[4] gives the following instructions for machining specimens when the surface and material directly beneath it may be affected by surface preparation: "Finish with a sharp tool and light cuts to prevent . . . cold working of the specimen." Concerning polishing of fatigue specimens, the Manual states: "Generally, any method which produces a smooth surface without cold working . . . will constitute good polishing."

In tests employing axial stresses, however, as in tension and compression tests, the average effects of this cold working generally have been considered of little importance. The ASTM Tentative Methods of Tension Testing of Metallic Materials (E 8 – 51 T)[5], while making no specific mention of possible effects of cold working during preparation of specimens, do state that "Improperly prepared test specimens often cause unsatisfactory test results." An earlier issue (E 8 – 36) mentioned specifically, however, that specimens should ". . . be machined in such a manner as to avoid leaving severe machining strains in the material."

In various studies at the Aluminum Research Laboratories it has been observed that the machining of tension test specimens produced significant effects upon the results of tests of annealed pure aluminum. Accordingly a study has been made to evaluate these effects, not only on pure aluminum but also on several wrought-aluminum alloys.

MATERIALS

The materials tested included a total of 15 compositions, as listed in Table I, ranging from 996A (99.6 per cent aluminum) with a yield strength of less than 3000 psi to 56S-O with a yield strength of about 24,000 psi. There were 13 compositions of $\frac{3}{4}$-in. diameter rod and 10 of 0.064-in. thick sheet. Each item of rod and sheet had been produced commercially in a cold-worked temper, except that the 63S rod was extruded to size.

TABLE I.—COMPOSITIONS OF MATERIALS TESTED.

Alloy Designation		Chemical Composition, per cent				
ASTM	Alcoa	Copper	Silicon	Manganese	Magnesium	Chromium
996A	CD1S	99.6 per cent minimum aluminum				
EC	EC	99.45 per cent minimum aluminum				
990A	2S	99.0 per cent minimum aluminum				
M1A	3S	...	...	1.2	...	...
MG11A	4S	...	...	1.2	1.0	...
CS41A	14S	4.4	0.8	0.8	0.4	...
CM41A	17S	4.0	...	0.5	0.5	...
CG42A	24S	4.5	...	0.6	1.5	...
CS41C	25S	4.5	0.8	0.8	...	...
G1A	B50S	...	...	...	1.2	...
GR20A	52S	...	...	...	2.5	0.25
GS11B	53S	...	0.7	...	1.3	0.25
...	56S	...	...	0.1	5.2	0.1
GS11A	61S	0.25	0.6	...	1.0	0.25
GS10A	63S	...	0.4	...	0.7	...

PROCEDURE

Four tension specimens were taken consecutively from a 30-in. length of each sample of rod, and were prepared for testing in the annealed temper. For most materials, duplicate lengths were used. The first specimen from each length was full-size, $\frac{3}{4}$-in. diameter. The other three were standard $\frac{1}{2}$-in. diameter threaded-end specimens. One of these was machined from the rod as received, and the other two were machined from the full-size rod after annealing. To eliminate any variables from annealing, the full-size specimen, the $\frac{1}{2}$-in.-diameter specimen machined before annealing, and the piece of rod for the two ½-in. diameter specimens to be machined after annealing, were annealed simultaneously in the same furnace. The machining of the specimen machined before annealing, and of one of those machined after annealing, was done in a lathe using cuts of normal depth consistent with good machining practice. The remaining specimen was machined using shallow cuts in order to obtain a minimum amount of cold working.

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[4] Manual on Fatigue Testing, Am. Soc. Testing Mats. (Issued as separate publication, *STP No. 91*).

[5] 1951 Supplement to 1949 Book of ASTM Standards, Part 1, P. 375; Part 2, p. 320.

TABLE II.—RESULTS OF TENSION TESTS OF ANNEALED ALUMINUM AND ALUMINUM ALLOY ROD.

Alloy and Temper Designation		Tensile Strength, psi				Yield Strength,[a] psi				Elongation in 4 × Diam, per cent			
		Full Size Specimen (Unmachined)	Machined Specimen			Full Size Specimen (Unmachined)	Machined Specimen			Full Size Specimen (Unmachined	Machined Specimen		
			Annealed after Machining	Machined after Annealing			Annealed after Machining	Machined after Annealing			Annealed after machining	Machined after Annealing	
ASTM	Alcoa			Standard cuts	Shallow cuts			Standard cuts	Shallow cuts			Standard cuts	Shallow cuts
996A-O	CD1S-O	9 900	10 000	10 100	10 000	2 700	2 500	5 700	4 300	65.0	54.0	47.5	51.0
EC-O	EC-O	12 800	13 300	13 500	13 300	4 400	4 400	6 600	6 000	46.7	46.0	43.0	44.0
990A-O	2S-O	12 600	13 000	13 100	13 100	4 100	4 100	5 900	5 600	53.6	45.0	42.0	42.0
M1A-O	3S-O	15 100	15 400	15 600	15 500	5 400	5 300	6 100	6 300	50.6	38.0	38.5	38.0
MG11A-O	4S-O	27 800	28 200	27 800	27 800	11 800	12 400	12 400	12 400	25.6	24.0	24.0	24.0
CS41A-O	14S-O	26 400	25 900	25 900	25 900	8 900	8 700	9 100	8 600	27.0	24.5	23.5	26.5
CM41A-O	17S-O	39 400	38 300	39 100	38 900	17 500	17 000	17 400	17 500	24.0	24.0	22.5	22.5
CS41C-O	25S-O	27 800	27 000	27 200	27 200	8 900	8 800	9 400	9 400	27.6	28.0	24.5	23.0
G1A-O	B50S-O	21 500	21 400	21 400	21 400	6 400	6 500	8 000	7 700	36.0	31.2	31.0	32.5
GR20A-O	52S-O	28 600	28 600	28 400	28 400	11 100	12 000	11 600	11 500	32.5	30.5	30.2	30.0
GS11B-O	53S-O	16 900	16 900	17 000	16 900	5 600	5 500	6 600	6 400	41.6	35.5	36.0	35.5
...	56S-O	45 000	45 000	46 000	44 200	23 100	24 100	23 800	24 200	29.0	30.0	30.0	30.0
GS10A-O	63S-O	12 200	12 300	12 400	12 400	4 000	4 000	5 400	5 400	55.2	41.5	42.2	41.5

[a] Offset equals 0.2 per cent, except for those alloys that had a yield point.

Longitudinal and transverse ½-in. wide tension specimens of each sample of sheet were prepared following a somewhat similar procedure with regard to annealing. Alternate blanks sheared from the sheet were divided into two groups. One group was machined from the sheet as received, and the other was machined after the sheet had been annealed. As in the case of the rod, the specimens that were machined before annealing, and the blanks from which the specimens were to be machined after annealing, were annealed simultaneously. All sheet specimens were machined by cross-milling from $\frac{13}{16}$-in. wide blanks, using normal procedure[6].

The tension tests were made in accordance with the ASTM Tentative Methods of Tension Testing of Metallic Materials (E 8 – 51 T). All tests of any one sample were made using the smallest suitable range of the same Amsler Universal Testing Machine of 20,000-lb maximum capacity. Yield strengths were determined using a Templin autographic extensometer[7]. Elongations in each test of rod were measured in a gage length equal to four times the diameter of the test section, and those of sheet in 2 in.

Discussion of Results

The average results of the tests of rod are summarized in Table II, and those for the sheet are summarized in Table III.

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[6] R. L. Templin, "Methods for Determining the Tensile Properties of Thin Sheet Metals," *Proceedings*, Am. Soc. Testing Mats, Vol. 27, Part II, p. 235 (1927).

[7] R. L. Templin, "An Automatic Autographic Extensometer for Use in Tension Tests of Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part II, p. 783 (1932).

In general the tensile strengths and yield strengths of the rod materials as determined using full-size specimens and ½-in. diameter specimens annealed after machining agreed within 2 or 3 per cent. Larger differences were observed in the elongation values, and, although the differences were not very consistent, there were general trends. This is illustrated in the upper part of Fig. 1, where the percentage differences in elongation values for the full-size specimens, based on the elongation values of the annealed ½-in. diameter specimens, are plotted against elongations and yield strengths of the latter specimens. For materials with low yield strengths, the elongation values are as much as ⅓ larger when using full-size specimens. One suggested explanation for this difference is that the full-size specimens were of uniform cross-section throughout their lengths, while the diameter of each machined specimen was 0.003 to 0.005 in. smaller at the center than at the ends of the gage length.

TABLE III.—AVERAGE RESULTS OF TENSION TESTS OF ANNEALED ALUMINUM AND ALUMINUM ALLOY SHEET.

Alloy and Temper Designation		Tensile Strength, psi				Yield Strength,[a] psi				Elongation in 2 in., per cent			
		Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
ASTM	Alcoa	Annealed after Machining	Machined after Annealing	Annealed after Machining	Machined after Annealing	Annealed after Machining	Machined after Annealing	Annealed after Machining	Machined after Annealing	Annealed after Machining	Machined after Annealing	Annealed after Machining	Machined after Annealing
996A-O	CD1S-O	10 400	10 500	10 600	10 600	3 400	4 100	3 400	4 000	40.4	40.0	33.0	34.9
990A-O	2S-O	12 600	12 500	12 200	12 200	4 100	4 600	4 000	4 600	37.8	38.8	38.5	37.8
M1A-O	3S-O	16 400	16 600	16 000	16 200	6 000	6 400	6 000	6 400	33.0	32.8	32.4	32.6
MG11A-O	4S-O	27 500	27 500	26 800	26 700	11 400	11 500	11 500	11 600	21.9	22.4	23.0	22.7
CM41A-O	17S-O	30 800	30 700	30 800	30 800	16 700	16 600	16 400	16 500	13.8	13.4	13.1	13.5
CG42A-O	24S-O	30 900	31 000	29 400	29 300	11 100	11 200	11 000	11 000	21.2	19.5	19.7	19.8
G1A-O	B50S-O	20 700	20 600	20 500	20 500	7 400	7 600	7 300	7 600	26.0	24.2	28.6	27.8
GR20A-O	52S-O	28 800	29 000	28 600	28 500	14 000	14 500	14 200	14 100	25.2	25.6	25.5	25.3
GS11B-O	53S-O	19 300	19 200	19 800	19 700	8 300	8 400	8 700	8 800	25.2	25.5	24.8	25.6
GS11A-O	61S-O	20 500	20 500	20 600	20 500	8 000	8 100	7 900	8 000	24.3	24.9	25.1	23.9

[a] Offset equals 0.2 per cent, except for those alloys that had a yield point.

When machined specimens of the rod were tested, the yield strengths of the lower strength materials were definitely affected by the procedure used in preparing the specimens. For example, the yield strength of the specimen of 996A (99.6 per cent aluminum) machined in the usual manner after annealing was more than double that of the specimen annealed after machining. This effect is illustrated in Fig. 2, where the yield strength determined using specimens machined after annealing is expressed as per cent increase in value as a result of machining. From this it can be seen that, for rod of aluminum and aluminum alloys having yield strengths below 10,000 psi, the cold work introduced by machining is significant when machined round specimens are used.

There appeared also to be a noticeable but less pronounced effect upon elongation of those materials having yield strengths below about 5000 psi, as shown in the lower part of Fig. 1. The elongation of the 996A was decreased about ⅛ when using specimens machined after annealing.

There appeared to be no definite effect upon tensile strength of any of the materials tested.

Generally the effects of machining were less in the testing of sheet than in the testing of rod, as shown in Fig. 2. This is reasonable because in round

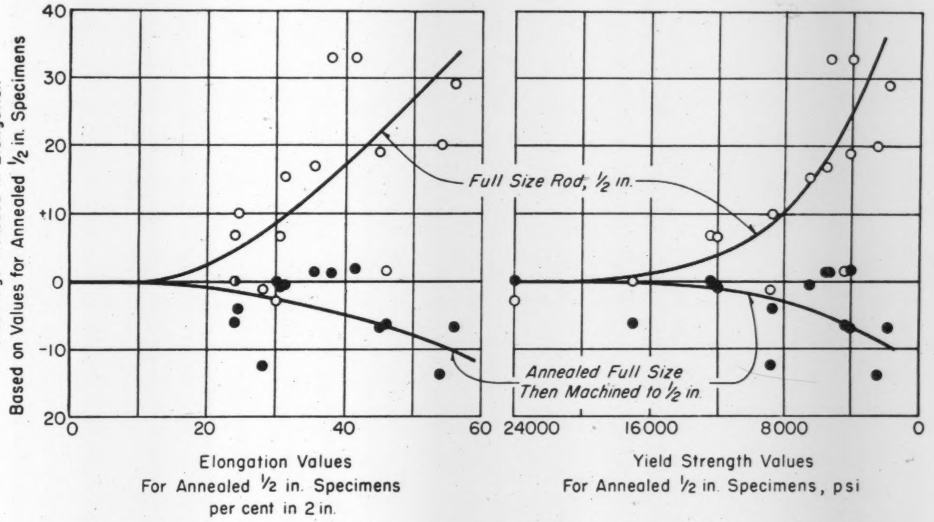

Fig. 1.—Elongation Values of Full-Size and Machined Specimens of Annealed Aluminum Alloys.

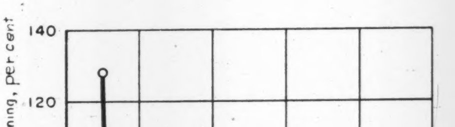

Fig. 2.—Effects of Machining on Yield Strength Values of Annealed Aluminum Alloys.

specimens the proportion of the total volume of the test section affected by the cold working introduced by machining is greater than for specimens milled from sheet. The effects on the yield strengths of aluminum and aluminum alloys that are less than 8000 psi still were large enough, however, to be significant. No definite effects upon tensile strength or elongation were observed.

The effects of machining specimens also vary with the size of specimen, being larger for the smaller sizes because a greater proportion of the cross-section is affected. This was demonstrated by a few tests of 3S rod using specimens ranging from $\frac{1}{2}$ in. to $\frac{1}{8}$ in. in diameter. When $\frac{1}{2}$-in. specimens were used, the difference in yield strength was 15 per cent, and when $\frac{1}{8}$-in. specimens were used, this difference increased to 35 per cent, without any effect on tensile strength or elongation.

The fact that the effect of machining upon yield strength was more than upon tensile strength or elongation is consistent with work previously reported by Templin.[8] He found that cold work not only had a greater effect upon yield strength than upon tensile strength, but that the rate of increase in yield strength was also much greater for small amounts of cold work than for larger amounts. For example, the increase in yield strength resulting from 1 per cent cold work is about 40 times as much as the increase in tensile strength.

The effects of machining upon the structure of one of the materials was studied by examining a ½-in. diameter tension specimen which had been machined after annealing. Examination was made both metallographically and by X-ray diffraction. The material chosen, 996A, was the one on which the effects of machining upon the tensile properties were largest. The metallographic examination indicated that the effects upon grain structure extended only about 0.0001 in. beneath the surface. The X-ray diffraction patterns, however, which were obtained by the oscillating back-reflection method, demonstrated definitely that a strained matrix extended about 0.035 in. from the surface, or throughout ¼ of the total cross-sectional area.

The use of shallower cuts in the machining of specimens had been proposed as a means of minimizing the effects of cold work. While some improvement was obtained in this manner, as can be seen in Table II, the reduction was insufficient to offer a practical solution to the problem. Nevertheless, it is quite obvious that the introduction of any cold work by machining of specimens of material having relatively low yield strengths should be minimized by using sharp tools and by taking cuts that are as light as practical to use.

The only way of completely eliminating machining effects in the tension testing of very soft metals seems to be by testing full size or, when this is impractical, by machining specimens from the material prior to the producer's final annealing operation. It is unsatisfactory to machine specimens from an annealed material and then reanneal, for the small and variable amount of cold work may result in grain growth, which in turn can have a significant effect upon the properties of the material.

Although only tension tests were made in this investigation it is reasonable to expect that machining would have similar effects upon determinations of compressive yield strength.

CONCLUSIONS

The following conclusions seem justified concerning the tension testing of annealed aluminum and aluminum alloys:

1. The cold work introduced in the machining of test specimens, even when the machining is done in such a manner as to minimize cold working, has a significant effect upon the values of yield strength for materials having low yield strengths. The effect on tensile strength is insignificant.

2. The yield strength values for annealed 996A (99.6 per cent aluminum) with a yield strength of about 2500 psi are more than doubled by machining round specimens from rod in the usual way. The effect is less for materials having higher yield strengths but does not become an insignificant factor until a yield strength of about 10,000 psi is reached.

3. The effects of machining round specimens upon elongation values are not as clearly defined, although it appears that machining after annealing results in lower elongation values for materials having yield strengths lower than about 5000 psi.

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[8] R. L. Templin, "Effects of Cold Working on Physical Properties of Metals," Technical Publication No. 238, Am. Inst. Mining and Metallurgical Engrs. (1929).

4. The effects of machining upon the yield strength values of sheet specimens are of smaller magnitude and are insignificant for materials having yield strengths of about 8000 psi or more. There is no appreciable effect upon elongation.

5. Since there are not many specifications requiring the determination of yield strength values for annealed aluminum or aluminum alloys, machined specimens can generally be used for inspection tests.

6. Cold work from machining should be minimized by using sharp tools and by taking light cuts when practical to do so.

7. Since reannealing of specimens after machining is not satisfactory, the only way of completely eliminating machining effects in the tension testing of annealed metals seems to be to use full-size specimens or, when this is impractical, to use specimens machined from a cold worked temper of the material (at least half-hard) before annealing.

Acknowledgment:

The authors acknowledge the assistance of C. W. Beals, who performed most of the tests, and the suggestions of F. M. Howell, Chief of the Mechanical Testing Division, under whose general direction the work was done.

RESTORATION OF DUCTILITY OF COLD-WORKED ALUMINUM, COPPER, AND LOW-CARBON STEEL BY MECHANICAL TREATMENT*

By H. N. Polakowski[1]

Synopsis

Experiments were carried out to show that mechanical treatments involving large alternating strains (>1 per cent) may improve substantially and rapidly the ductility of certain common metals in the cold-worked condition. The results presented refer to cold-drawn or cold-rolled (to 15 to 60 per cent) aluminum (99.6 per cent Al), 2S and 3S alloys, copper, and non-aging low-carbon steel.

Reversed bending cycles were generally employed, but reversed torsion was equally efficient on aluminum rods. In many cases the tensile elongation value was more than doubled after a few cycles, the Vickers hardness, yield and tensile strength, decreasing at the same time.

The findings may be of practical interest, by showing that the mechanical properties of cold-rolled sheets or cold-drawn bars can be substantially modified by various leveling and straightening treatments.

The results obtained are reelated to previous work of Moore and Jasper, Dalby, and Kenyon, and to the author's invetisgations on the Bauschinger effect. An analysis of the phenomenon is given, based upon a pure stress concept.

On this concept, one should expect initially work-hardened aluminum and copper to soften gradually under the action of the fatigue stress. If this is confirmed, the relatively small improvement of fatigue strength achieved by cold-working these and certain other non-ferrous metals could be accounted for by such partial retrogression of the work-hardened state.

This paper is primarily concerned with the effects of mechanical treatment involving large alternating deformations on the ductility and strength properties of certain common metals in the cold-drawn or cold-rolled condition.

Mechanical treatments of this type frequently take place in the metal manufacturing industries. Flattening of sheets in roller levelers, for example, or straightening of bars in multi-roll or rotary-head rectifiers, or even coiling of cold-drawn rod (particularly of heavier section) belong to this class.

The effect of these and similar processes on the mechanical properties of initially work-hardened material may be of considerable practical and fundamental interest, both immediate and potential. Yet as far as the author is aware, published information on this subject is almost nonexistent. Furthermore, no attempt was made to correlate various pertinent but thinly scattered observations in a systematic manner and to draw some general conclusions from them. This circumstance prompted the work described herein which is of imitative character and carried out with very simple means.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Imperial Chemical Industries Research Fellow, Metallurgical Dept., University College, Swansea, Great Britain.

Although in the experiments reported here only large cyclic deformations were employed, the results obtained seem to bear on some fatigue properties of cold-worked metals, unexplained hitherto. In consequence, this relationship received attention in the discussion parts of the paper.

BACKGROUND AND SCOPE OF INVESTIGATION

It has been known for some time that the loss of ductility suffered by a metal on cold working can be partly repaired by a subsequent plastic strain of an opposite sign to that used first (**1**, **2**, **3**).[2] This phenomenon is intimately associated with the Bauschinger effect and is due to work softening by which the former is accompanied (**4**).

Most of the experimental work done in the past on the restoration of ductility of cold-worked metals by purely mechanical methods (that is, without the help of heat) was confined to the simplest deformation methods. For example, the small residual elongation of a twisted bar could be increased by subjecting it to torsion in the opposite direction to that used first (**1**, **2**). An equivalent effect was obtained when a prestretched bar was compressed in the axial direction (**3**). Complex deformation processes such as drawing through a die or rolling cannot be "reversed" in the strictest sense. Compression of a rolled sheet of cold-drawn rod in the direction opposite to the elongation received during working represents probably the nearest approach to a "reversal." A procedure of this type is theoretically feasible but highly impractical because of the difficulty in preventing buckling. Furthermore, experiments on these lines are unlikely to add much fundamental knowledge to what is already known from tension-compression tests.

A more promising approach to exploring the nature, possibilities, and limits of mechanically produced softening was afforded by an incidental observation made years ago by Dalby (**5**) during alternating torsion tests on hard-drawn copper bars. He has found that contrary to what was observed with initially soft (annealed, normalized) metals, the successive torque-twist curves of the hard specimen ran a little below the preceding ones. This indicated that the copper must have softened somewhat on each reversal instead of being hardened still more. Dalby did not pay much attention to this fact nor did he try to explain it.

In a recent ASTM paper (**6**), Kenyon reported that soft "islands" are sometimes developed on the periphery of hard-drawn copper wire when subjected to prolonged fatigue testing by alternating flexure. From his conclusions it appears that he relates his finding to the "self-annealing" effect which is known for many years to occur in *heavily* cold-worked copper (**7**, **8**). Kenyon's wire was severely worked, showing a Knoop hardness of over 130 points.

The present author's previous work on the Bauschinger effect (**4**, **9**) led him to formulate the following tentative conclusion (**9**):

> "Work softening occurs whenever the method of cold working used tends to produce (in the metal) an internal stress system different from that left after the preceding treatment, irrespective of whether the latter was of mechanical or thermal nature."

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[2] **The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1097.**

This has been employed to account for a variety of practically noted phenomena, and in particular for an interesting observation made by Moore and Jasper in the course of their "understressing" experiments (10). These authors established that while carbon steels in an initially soft condition hardened up appreciably as a result of an understressing treatment, almost no extra hardening was caused in such steels when similarly treated in the sorbitic state.

The conclusion expounded above may appear rather sweeping at first sight. In fact it is subject to limitations when the degree of cold deformation (or magnitude of internal stress) caused by the "preceding treatment" is small. For initial deformations of 15 per cent or more which are used in this work, these limitations do not apply, as will be seen later. At any rate, it is plain that all three examples quoted above seem to fit into the range of its validity.

Dalby's copper was heavily drawn and later subjected to torsion which clearly tends to build up a different system of internal stress than does drawing. Kenyon used similar material and subjected it to bending. Moore and Jasper cold worked a steel originally hardened by thermal treatment, and such treatment will always produce internal strains of a different character than any type of cold work.

The above indicates that softening of cold-worked metals by means of different types of working procedures than those used first is a clear possibility. It remains only to prove that: (*a*) such softening can and most likely does occur in everyday practice, probably without the knowledge of those concerned in many cases; (*b*) that in some circumstances it may affect the properties of the metal to a practically important degree; (*c*) that it occurs in various metals, and at degrees of work-hardening at which "self-annealing" is not known to occur.

Such proof is given in this paper.

EXPERIMENTAL PROCEDURE AND MATERIALS

The experiments were planned on the following premises: (*a*) Their aim is not to provide a set of detailed data relating to some carefully selected materials but to obtain general information of fundamental character; (*b*) the results obtained must be easily and instantaneously reproducible; (*c*) the experimental method should be as simple as possible. The last condition was dictated by external circumstances since the laboratory with which the author is associated is not equipped with a roller-leveler or similar machine.

Reversed bending and reversed torsion were adopted as treatment methods for cold-drawn rods. For cold-rolled strip samples, only reversed bending could be used. All torsion was done on a small bench-type wire torsion tester having a maximum diameter capacity of 0.25 in. Bending, or rather coiling, was carried out by wrapping the specimen rods or strips around smoothly finished mandrel of various diameters. Some of the strips were coiled to form small, single-width coils with one layer on top of the other. But it has been found that winding the strips in a spiral gives identical results with respect to the final properties as the former, more tedious method. Consequently, winding in a spiral was ultimately adopted as the simpler one.

The term "cycle" is used here in the same sense as in fatigue testing. In bending it means winding the specimen around the mandrel, straightening, winding it in the opposite direction, and straightening it out finally. In this way the extreme fibers of the metal suffer plastic deformation varying from a maximum extension to a maximum compression, while the dimensions remain unaltered. When more than one cycle had to be applied, then each consecutive one was performed in a plane at right angles to that of the preceding cycle. This practice secured a more uniform working of the material. The diameters of the mandrel were varied from 1.25 to 6.5 in.

In the torsion experiments, a full cycle consisted in twisting the sample rod over the required angle clockwise, untwisting it back to zero position, followed by a counter-clockwise twist over the same angle, and a return to zero. The active twisted length, determined by the distance between the grip-faces, was 8 in. in all the tests. The angle of twist was ±45 deg per in., this corresponding to a torsion schedule 0/+360 deg/0/−360 deg/0 on the hand wheel. With the 0.250-in. rods, the shearing strain was $\tan \varphi = 0.098$. The effect of varying the total twisting angle between ±270 and ±450 deg had little influence upon the final results. All twisting was carried out under a light longitudinal tension of 20 lb which facilitated keeping the specimens straight by taking off the axial thrust. The bent material did, of course, require additional straightening in a vise.

TABLE I.—EXPERIMENTAL MATERIALS.

Material	Size	Mark	Cold-worked, per cent	Tensile Strength, psi	Vickers Hardness, 5-kg Load	Elongation in 4 in., per cent
Electrical purity aluminum (⩾99.6% Al)	Rod, 0.250 in diam.	Al-a	0	10 800	23	30.6
		Al-15	15.6	13 500	33/34	10.3
		Al-25	25.6	14 900	35/36	7.4
		Al-55	55.0	17 000	38/39	5.5
Commercial quality aluminum (⩾99.0% Al)	Rod, 0.250 in. diam.	2S-15	15.6	16 500	40/41	7.9
		2S-25	25.6	19 300	43/44	5.4
		2S-60	61.0	19 900	45/47	3.2
Al-Mn alloy (nom. 1.2% Mn)	Rod, 0.250 in. diam.	3S-15	15.6	23 300	53/55	10.8
		3S-25	25.6	25 100	55/57	8.4
High-conductivity copper	0.313 in diam	Cu-18	18.5	43 000	100/105	11.8
	Strip, 0.060 × 0.625 in.	Cu-a	0	33 000	43	47.8
		Cu-35	~35[a]	48 000	107	4.7
Stabilized low-carbon steel	0.032 × 1 in.	St-22	15.6	63 500	...	8.9
	0.0295 × 1 in.	St-22	21.9	69 000	...	4.9

[a] Estimated.

Finally, each specimen was pulled in a tension machine to destruction. A 0.5/1/2.5/5 ton Amsler pendulum weight machine was used with a constant speed of straining of 0.063 in. per min per in. of gage length. The gage length was 4 in. in all cases and the extensometer curves were recorded autographically at a 2:1 magnification.

The main experimental materials are listed in Table I.

Two points were taken into account in their selection: first, that they should be cold worked to a moderate degree only; and second, that they should be practically free from precipitation hardening effects. The first condition eliminated the possibility of self-annealing; the fulfilment of the second removed the danger of introducing masking effects which might have overshadowed the mechanical softening phenomenon. (It may be recalled, that cold working promotes aging in general.)

All aluminum rods were drawn to uniform final diameter of 0.250 in. through tungsten carbide dies, wound on a pulley, and afterwards straightened on a rotary head machine. Single drafts were applied for the 15.6 and 25.6 per cent reductions, and three successive drafts for 55 and 61 per cent over-all reductions. The copper rod Cu-18 was supplied in the hand-straightened state.

The narrow copper strip was received as cold-rolled (Cu-35). A part of the batch has been annealed for 1 hr at 600 C to get the soft form Cu-O. Some aluminum-stabilized, nonaging low-carbon steel was available in the form of cold-reduced, subcritically annealed, skin-passed sheet, 0.038 in. thick. Suitable pieces of strip were cut therefrom and reduced to the thicknesses indicated in Table I on a 6 by 6-in. laboratory rolling mill. Because of previous temper rolling, the strip in the as-received state exhibited no "jog" at the yield point. Its yield strength was about 23,600 psi, tensile strength 46,000 psi, elongation in 4 in. about 34 per cent, and its Vickers hardness was 96/98. The chemical analysis was as follows (in per cent): 0.080 carbon; 0.029 sulfur; 0.019 phosphorus; 0.37 manganese; and some residual elements of lesser importance. The steel was killed with aluminum in the mold.

RESULTS

Drawn Rods:

A number of resulting load-extension curves obtained on aluminum (2S and 3S) is shown in Fig. 1.

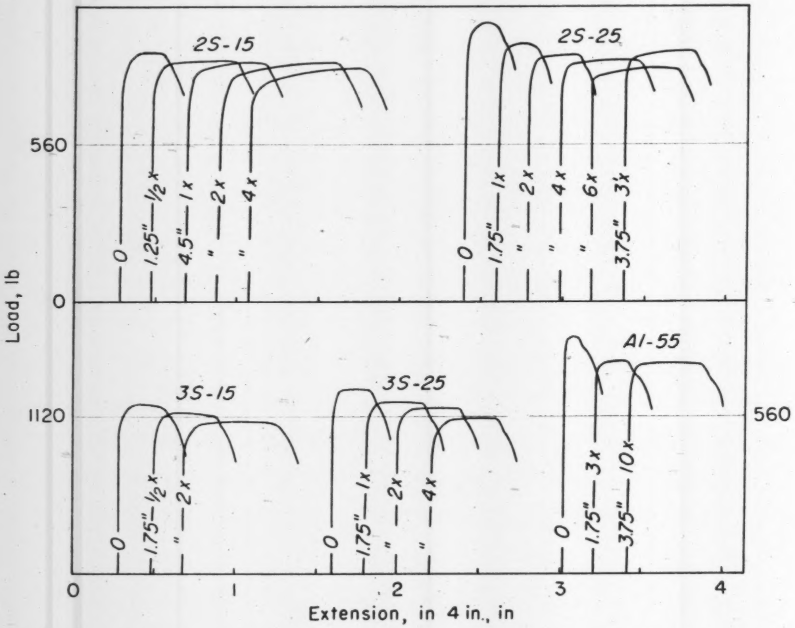

FIG. 1.—Effect of Reversed Bending on Ductility and Strength Properties of Cold-Drawn Aluminum (2S, and 3S).

Lower numbers on curves in all diagrams denote diameters of mandrels; upper ones—the number of cycles applied. Specimens "O" are as-drawn (or as-annealed where appropriate).

The curves, O, are those of the metal in the as-drawn condition. In all other curves the lower figure denotes the diameter of the mandrel over which the rods were bent and the upper the number of cycles applied.

It is seen that in each case reversed bending resulted in a considerable increase of ductility, in many instances more than two fold compared with the original value. At the same time there was a systematic fall of yield and tensile strength. Both the diameter of the mandrel and also the number of cycles influence the rate and magnitude of the phenomenon. Generally, for equal numbers of reversals the rate at which the ductility is restored is greater when the ratio of mandrel diameter to rod diameter (D/d) is low, say, between 5 and 8. With mandrels of still smaller diameter ($D/d < 4$) the effect is reversed and the ductility of the specimen rod falls rapidly. The rods become, however, heavily distorted, and these results are not reproduced. The shape of the diagrams obtained with 2S-60 altered in the same way as with Al-55, but the changes were less pronounced.

Figure 2 shows load-extension curves of aluminum specimens which were repeatedly twisted in the way described previously. The maximum number of cycles applied was 32. The changes of ductility shown by tensile elongation are plotted on the bottom of Fig. 3. It is seen that the soft rods Al-a harden systematically, while the cold-worked materials become more and more ductile, the elongation value reaching a maximum after 8 or 16 applications. Later it appears to fall away due possibly to incipient mechanical disintegration.

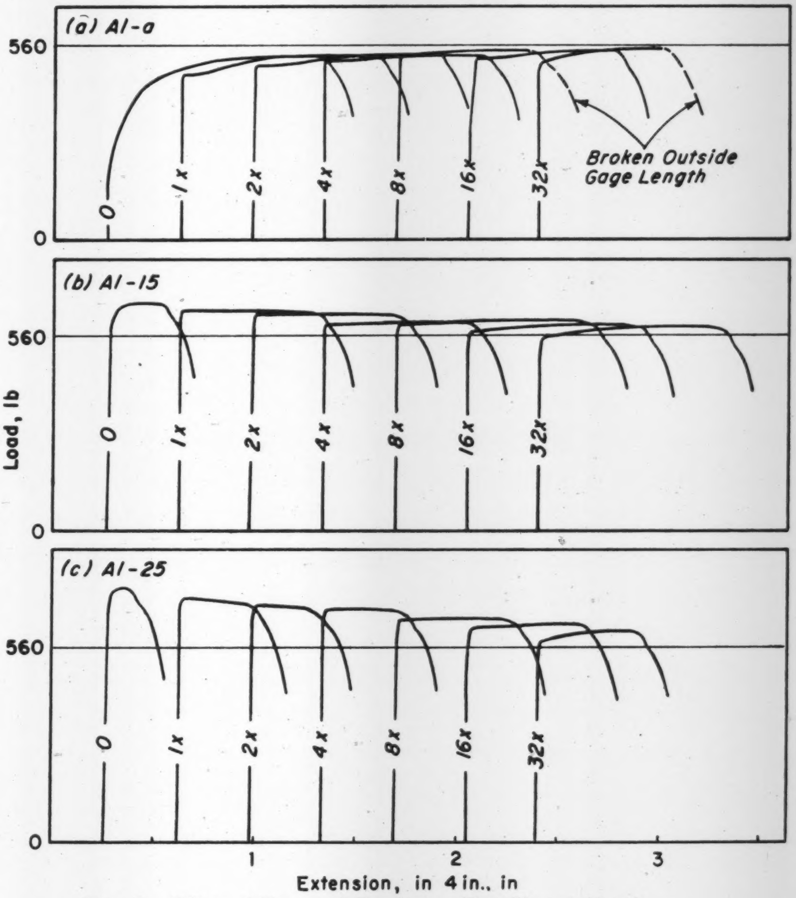

FIG. 2.—Effect of Reversed Torsion on Ductility of Aluminum.

These diagrams include some points obtained from duplicate tests which, to avoid confusion, are not depicted in Fig. 2. The decrease of yield strength is actually less than it would appear from (*b*) and (*c*) in Fig. 2, because repeated torsion is accompanied by a slow but systematic thinning of the specimens thus reducing the cross-section upon which the measured tensile load is acting. For example, after 32 reversals the diameter of Al-15 decreased from 0.250 to 0.240 in. (4 per cent).

It is interesting to note that the spectacular increase of ductility by up to 150 per cent was not accompanied by a comparable fall of Vickers hardness. The maximum drop observed with Al-15 and Al-25 was only 2 points from the values listed in Table I. These hardness measurements were made on the surface of the rods.

The diagrams in Fig. 4 refer to repeated bending of copper. The elongation value of Cu-18 was nearly doubled after only two cycles over a mandrel of 3.75 in. diameter. The specimens Cu-33 were drawn down from Cu-18 with an intermediate anneal at 0.312 in. diameter. The reduced rod had thus a final diameter of 0.255 in.

Surprisingly enough, reversed torsion applied to drawn copper gave opposite results than with aluminum, leading to a further loss of ductility.

Rolled Strips:

Some representative results obtained with copper strip are shown in Fig. 5. It is seen that the load extension curves of the initially work-hardened metal Cu-35 follow one another in the expected way.

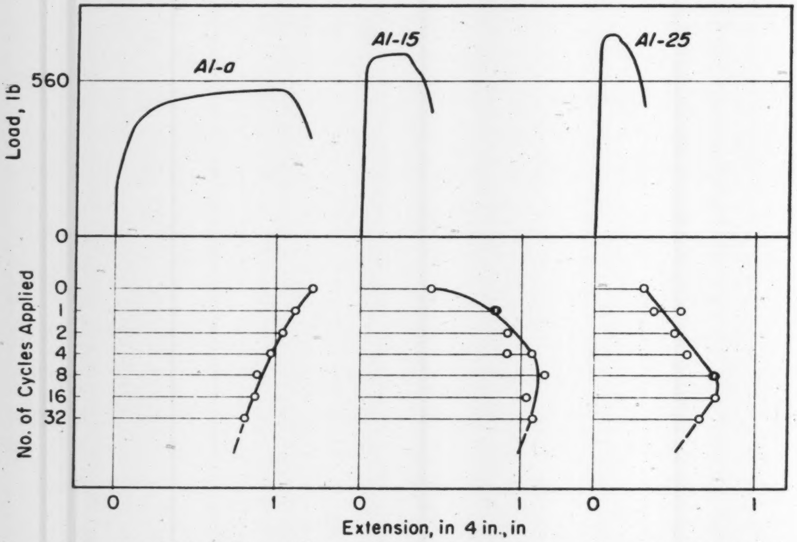

FIG. 3.—Elongation Values Plotted from Fig. 2 as Function on Number of Torsion Cycles Applied.

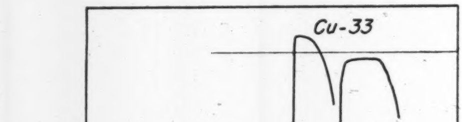

FIG. 4.—Effect of Reversed Bending on Tensile Properties of Cold-Drawn Copper. Mandrels of 3.75 in. Diameter Throughout.

By employing a mandrel of fairly large diameter (3.75 in.) the tedious procedure of coiling and uncoiling the strip was eliminated with the short 12-in. pieces used. This enabled a large number of cycles to be performed rapidly without the danger of disfiguring the strip.

The fifth and sixth curves indicate that even after 50 reversals the maximum ductility was apparently not attained. The hardness fell from the initial value of 107 to 94 points after 20 cycles, and to 87 after 50.

Specimens Cu-23 were obtained by rolling down Cu-a (= annealed Cu-35) from 0.060 to 0.046 in.

As could be expected, repeated reversed bending of the dead-soft metal Cu-a causes a rise of the yield point and a fall of the elongation. But the author's experience suggests that alternating flexing over a constant radius finally brings the strip to a kind of "cyclic state." This means that after a finite and rather reasonable number of reversals the metal cases to harden any further. In this particular experiment such a state of saturation was reached after only about 20 reversals and the load-extension curve assumed a shape which practically did not alter any more. This curve was almost identical with that obtained after 50 cycles (last curve on the right). The Vickers hardness also remained constant and equal to 80 points over this range.

In other words, the specimen became cold worked to some definite limited, but any additional hardening induced during bending was immediately lost upon straightening.

One might speculate as to whether the initially hard samples Cu-35 converge to the same cyclic condition as does Cu-a, when wrapped over the same diameter (over and back). With the technique employed, it was not possible to give a reply to this question as yet. However, the trend in this direction was quite obvious.

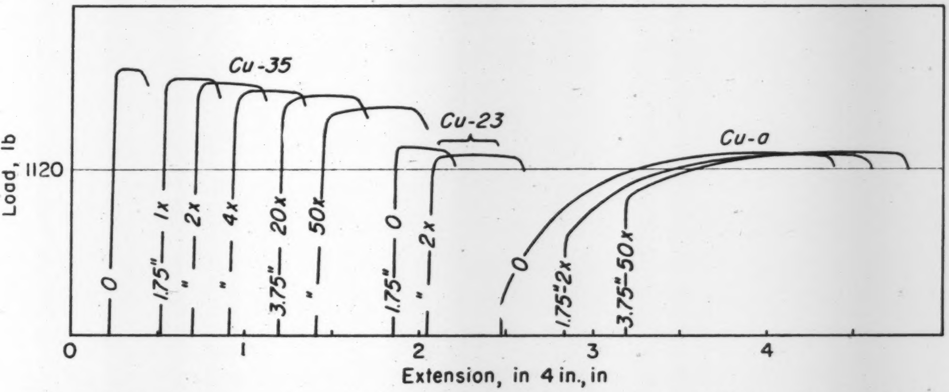

FIG. 5.—Effect of Reversed Bending on Tensile Properties of Annealed (Cu-a), and Cold-Rolled (Cu-23, Cu-35) Copper Strip.

In the sample tests depicted in Fig. 6, the diameter of the mandrel over which the strips were wound was 1.25 in. in all cases.

The aluminum strips were cut from a commercial-quality sheet purchased from a dealer as "aluminum." Many other experiments made on materials of the 2S-class gave similar results as those presented and they need not be reproduced.

Finally, the right-hand side of Fig. 6 shows that in spite of its high melting point and recrystallisation temperature, combined with a fairly small reduction by cold rolling, steel St behaves precisely like the much softer aluminum and copper.

DISCUSSION

A satisfactory, all-round explanation for the effects reported is not yet forthcoming. The difficulty lies perhaps not so much with the main phenomenon but rather with the "marginal" effects.

It is not easy to understand, for example, why the enormous increase of ductility of Al-15 and Al-25 in Figs. 2 and 3 is not accompanied by a proportional fall of Vickers hardness. Further, why was the ductility of drawn copper improved by reversed bending but worsened by cyclic torsion? Incidentally, the latter observation would seem to be in variance with what should be expected from Dalby's result. Both questions clearly call for further inquiry.

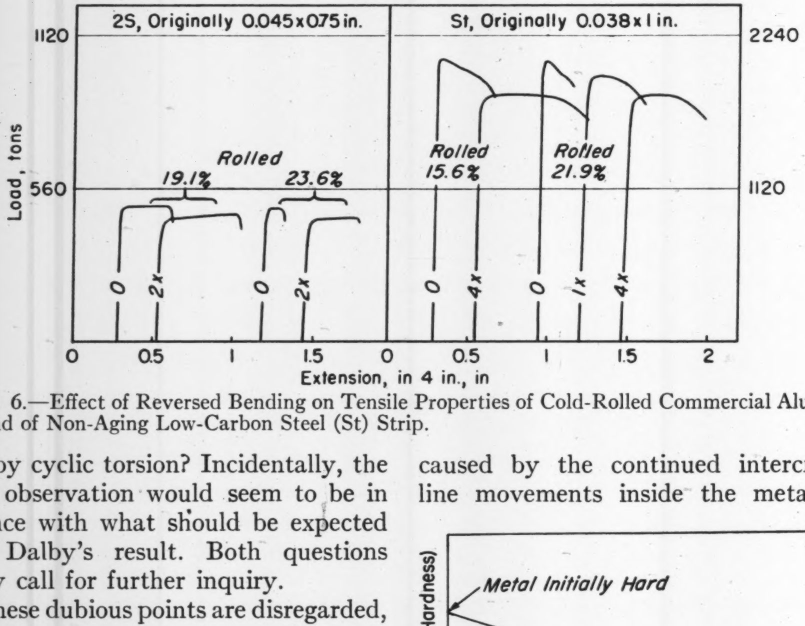

FIG. 6.—Effect of Reversed Bending on Tensile Properties of Cold-Rolled Commercial Aluminum (2S) and of Non-Aging Low-Carbon Steel (St) Strip.

If these dubious points are disregarded, a rough interpretation of the findings can be suggested on the following lines:

When a work-hardened metal is further coldworked by a different method than that used first, the deformation structure (orientation) left after the first procedure is gradually replaced by one characteristic for the second method. The initial stage of this structural reorientation is associated with a more or less pronounced Bauschinger effect and with transient mechanical softening (4, 9).

If the second deformation process is continued, additional work hardening will eventually occur and this will lead to a further exhaustion of ductility. By interrupting the second process at, or near the point of maximum transient softening (9), a slight improvement of the elongation value will be found compared with its value at the end of the first process. If now the direction of the second process is reversed and working is carried forward to a small extent, the direction reversed once more, and so forth, then each consecutive cycle will contribute toward the gradual cancellation of the original deformation structure. This will be caused by the continued intercrystalline movements inside the metal, the

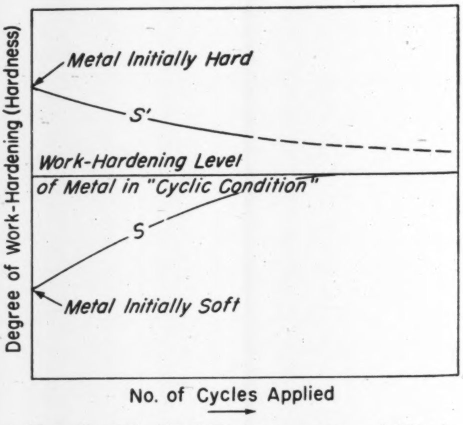

FIG. 7.—Idealized Representation of Hardness Changes in Initially Soft and in Heavily Cold-Worked Metal When Subject to Stress Cycles of Equal Amplitude.

individual crystals (or blocks) tending to assume positions most favorable with respect to the "easy-slip" direction characteristic for the second (cyclic) deformation method.

After a finite number of reversals there will be practically no trace of the orientation left after the first process except of some residual work hardening which forms a kind of "background" for the completely reversible cyclic deformation. It may be recalled that the existence of two types of work hardening, a reversible and irreversible, has been already postulated by Kochendörfer (11). He termed the first type "stress hardening," and the second "atomic hardening"; the first is mechanically reversible and associated with the Bauschinger effect, whereas the other is removable only by a recrystallisation heat treatment.

Some support is given to this concept by the results shown in Fig. 5, as illustrated by the diagram in Fig. 7.

The soft copper Cu-a reached the "cyclic state" after only about 20 large strain cycles were applied to it. The corresponding Vickers hardness was 80 points. The much harder metal Cu-35 kept on softening after 50 reversals of the same amplitude showing a fall of hardness from the initial 107 points to 87. While the tests had to be discontinued at this stage, the trend to a common cyclic condition was there. The cyclic strain in these experiments was $\pm(0.060 \div 3.75) \times 100 = \pm1.6$ per cent. A single application of a strain of this magnitude would bring about a hardness increase from the initial 43 to about 50 Vickers. The difference between this figure and the actual 80 points represents apparently the accumulated "atomic," irreversible work hardening.

Once brought to the cyclic state, the "base"-hardness will not alter any more (except of cyclic changes) irrespective of the original condition of the metal. The cyclic deformations do not promote cumulative work hardening because work softening is operative on each reversal and it offsets the cold work introduced in the immediately preceding phase.

Instead of the large reversed strains, cycles of smaller strain amplitude can be employed. Such procedure will generally depress the work hardening level at which the cyclic condition is attained. Supporting evidence of the type required was obtained by the author in repeated torsion tests on 0.2 and 0.7 per cent carbon steels with respectively 130 and 245 Vickers hardness numbers in the normalized condition. The final hardening level in terms of either hardness or yield strength was determined essentially by the amplitude of the cycles and not by their number.

While the above holds for initially annealed or normalized metals, the situation is different with metals which were substantially cold worked before cyclic straining is applied to them. Strain-softening during reversed deformation is a long-range phenomenon which develops gradually, and for metals of the type used in this work the maximum softening is reached between 5 and 8 per cent of linear strain (4). Thus, when the cycle amplitude is reduced, the strain-softening effect accompanying a single cycle is less pronounced and the rate at which the original cold-worked structure is being "stripped off" is thereby slowed down. Accordingly, the new cyclic condition will be attained after a greater number of strain reversals than would be the case with the larger amplitude. A visual interpolation of the curves 2S-15 and 2S-25 in Fig. 1, or extrapolation of those for Cu-35 in Fig. 5, illustrates this differential rate adequately. Nevertheless, a more pronounced final effect could be obtained even with a larger mandrel provided the number of cycles was sufficiently high.

The above reasoning is admittedly of a purely mechanistic character and neglects the metallurgical and metal-physical aspects of the issue. Thus it provides only a tool for arranging the experimental facts in a more or less systematic manner without pretending to explain their ultimate cause. Substantially in the same form, this concept has been formulated prior to starting the experiments, and it enabled the author to predict correctly the kind of results to be expected.

It is now appropriate to show by way of example, how the above concept can be used to explain certain practical observations, the nature and mechanism of which is not yet well understood.

In the manufacture of copper wire for electric conductors it was found that the final strength of the drawn wire depends not only on the reduction received but also on the diameter of the pulleys (capstans). With small diameter pulleys the tensile strength of the wire is markedly less than when large ones are employed (**12**). Obviously, the bending of the drawn metal around a drum followed by unbending is bound to cause some softening, its degree increasing as the capstan diameter is gradually reduced. Since the wire is reduced in a number of stages (drafts), it suffers several reversed bends which produce a cumulative effect on the final tensile properties in the manner already discussed.

The pattern of behavior represented by Fig. 7 also suggests a possible explanation for the peculiar fatigue properties of certain ferrous metals and alloys. As is well known, cold working is less effective in raising the endurance limit of some qualities of aluminum, copper, phosphor-bronze, and brass, than is the case with steel (**10, 13, 14**). Cold drawing or cold rolling may more than double the tensile and yield strength of the metal, and yet the fatigue strength will improve only 25 to 50 per cent, and sometimes less than that. If it could be proved that these metals, after initial cold working, soften progressively under fatigue loads on the lines of curve S' in Fig. 7, the aforesaid phenomenon could be accounted for. It is not too difficult to visualize that even a relatively slight softening of a fatigue specimen as a whole may be accompanied by a substantially greater effect in certain suitably orientated grains. The fatigue crack may then start in one of those weakened spots.

Conversely, these metals become work hardened when subject to fatigue stressing in the soft condition. The ultimate degree of hardening reached in this way may be comparable with that of the "soft spot" in the previous case.

Kenyon's microscopic evidence (**6**) may be regarded as a pointer indicating the feasibility of the scheme just presented. The results of tension tests on fatigued metals reported earlier by Czochralski and Henkel (**15**), while inconclusive, show a trend in the expected direction and hence lend indirect support to the present author's idea. However, in view of the fundamental importance of the problem, systematic experiments are being prepared now in order to settle the issue by means of direct mechanical tests. Their results will be made known in due course.

CONCLUSIONS

The experimental data obtained and their discussion can be summarized in the following:

1. Cold-worked aluminum (99.6 per cent aluminum; 99.0 per cent aluminum; aluminum + 1.2 per cent manganese), copper, and non-aging low-carbon steel soften appreciably when subject to mechanical treatment involving cyclic bending.

2. This softening is manifested by a considerable increase of ductility (measured by the total elongation in tension), and by a simultaneous fall of yield and tensile strength, and Vickers hardness.

3. The effect may be of direct interest to those who employ various types of levelers, straightening machines, and the

like for flattening cold-rolled sheets or rectifying drawn bars.

4. A similar restoration of ductility was observed with the investigated aluminium qualities when cyclic torsion was employed instead of bending.

5. It is unlikely that the phenomenon is due to an acceleration of "self-annealing" since the bulk of the experimental materials received only 15 to 35 per cent working by cold drawing or rolling.

6. The effect may or may not occur in metals which are liable to precipitation hardening of any type. A comparative investigation on these lines is contemplated.

7. The experimental findings are discussed in the light of background knowledge and related to the author's previous work on the Baushinger effect and on work softening.

8. A tentative interpretation of the results on a pure stress basis is presented.

9. It is suggested that the softening of certain work-hardened non-ferrous metals under cyclic stressing may be responsible for the relatively small improvement of their fatigue properties caused by cold working. Experiments on these lines are in hand.

Acknowledgment:

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PLASTIC STRESS-STRAIN RELATIONS FOR BIAXIAL TENSION AND VARIABLE STRESS RATIOS*

By Joseph Marin[1] and L. W. Hu[1]

Synopsis

The main objective of this investigation was to determine the validity of the flow theory of plasticity and the correctness of the assumptions made in this theory. For this purpose, plastic stress-strain relations for biaxial tensile stresses were determined for a 14S-T4 aluminum alloy. The biaxial tensile stresses were produced by subjecting a thin-walled tubular specimen to axial tension and internal pressure.

The usual *constant stress ratio tests* showed that the biaxial yield strength agrees best with the distortion energy theory, while both the biaxial nominal ultimate and true fracture strengths agree best with the maximum stress theory. The ductility for biaxial stresses was found to decrease with increase in the biaxiality of the stresses. When the ductility is measured by the significant strains at fracture, there was found to be approximate agreement between theory and the test results.

In one type of test, a stress was applied in the axial direction of the tube to a selected plastic strain value, and stress was then applied in the lateral direction. The results obtained from these tests support the flow rather than the slip theory.

A second type of special tests consisted in first applying a stress in the axial direction of the tubular specimen, removing this stress, and then applying a stress in the perpendicular lateral direction. These tests showed that the assumption of "isotropic yielding" is valid provided the initial isotropy of the material is considered.

A third kind of special tests consisted in first applying the lateral stress to some value and then the axial stress in increments. These tests show that the path of loading has little influence on the plastic stress-strain relations and do not confirm the flow theory.

A fourth type of tests, made to determine whether the distortion energy theory or maximum shear theory agreed best with the test results, showed that neither theory agrees with the actual values, but that the maximum shear theory is in much closer agreement than the distortion energy theory.

Many theories have been proposed for defining stress-strain relations for combined stresses in the plastic range based on the simple tension plastic stress-strain relation of the material. At the present time, there is not sufficient experimental evidence to prove which theory agrees best with the test data. In the past, most investigations have been conducted for biaxial stresses under loading conditions that produce a constant principal stress ratio. There are some exceptions, for example, a study on a magnesium alloy reported by Dorn. (1)[2] Constant stress ratio tests, however, do not distinguish between the flow and deformation type theories,[3] and, for this reason, the main emphasis in this investigation was placed on special and variable stress ratio tests in order to determine the validity of the flow theory. The results reported in this paper deal with biaxial tensile stresses.

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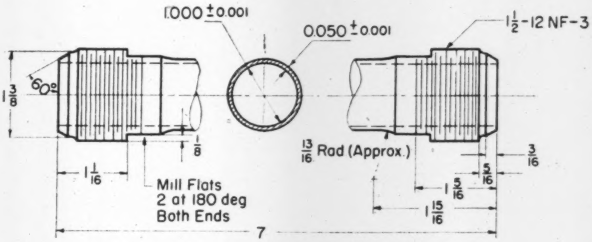

FIG. 1.—Tubular Specimen.
Note.—Inner and outer surfaces of tube must be polished smooth with 9/0 metallic cloth.

Material Tested and Specimen:

The material tested was an aluminum alloy designated as 14S-T4. The material was supplied in the form of hot-rolled machined cylinders, 7$\frac{1}{4}$ in. long by 1$\frac{5}{8}$ in. O.D. and $\frac{11}{16}$ in. bore. The normal composition, in addition to aluminum and normal impurities, consists of 4.4 per cent copper, 0.8 per cent silicon, 0.8 per cent manganese, and 0.4 per cent magnesium. The Research Laboratories of the Aluminum Company of America supplied control data on the yield strength, tensile strength, and ductility, which data provide information on the degree of anisotropy of the specimens. For this purpose, specimens taken from the cylinders were tested in the axial, lateral, and diagonal directions. The average values of the properties were: yield strength, 36,000 psi ± 10.4 per cent; tensile strength, 61,500 psi ± 2.8 per cent; elongation in 4 diameters, 21.4 per cent ± 4.5 per cent. The data supplied showed that only about one-half the percentage variations in strength was due to anisotropy, the remaining difference being due to normal variations in the material.

The dimensions of the machined specimen are given in Fig. 1. The specimen used had an over-all length of 7 in. with an intermediate length of 3$\frac{1}{8}$ in. of reduced wall thickness. The wall thickness was about 0.050 ± 0.001 in. Both the inside and outside surfaces of the specimens were machined. The wall thickness of the tubular specimens was measured

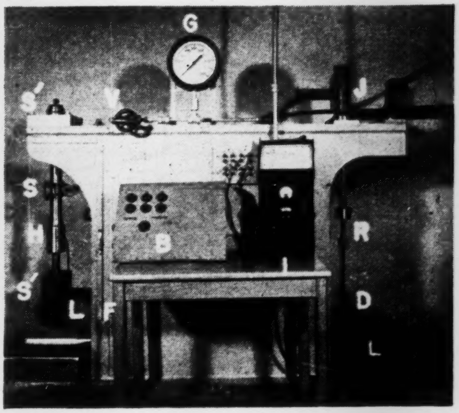

FIG. 2.—Testing Machine.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1123.

[3] When reference is made to the flow and deformation theories, the simple theories based on the octahedral stress and strain are intended.

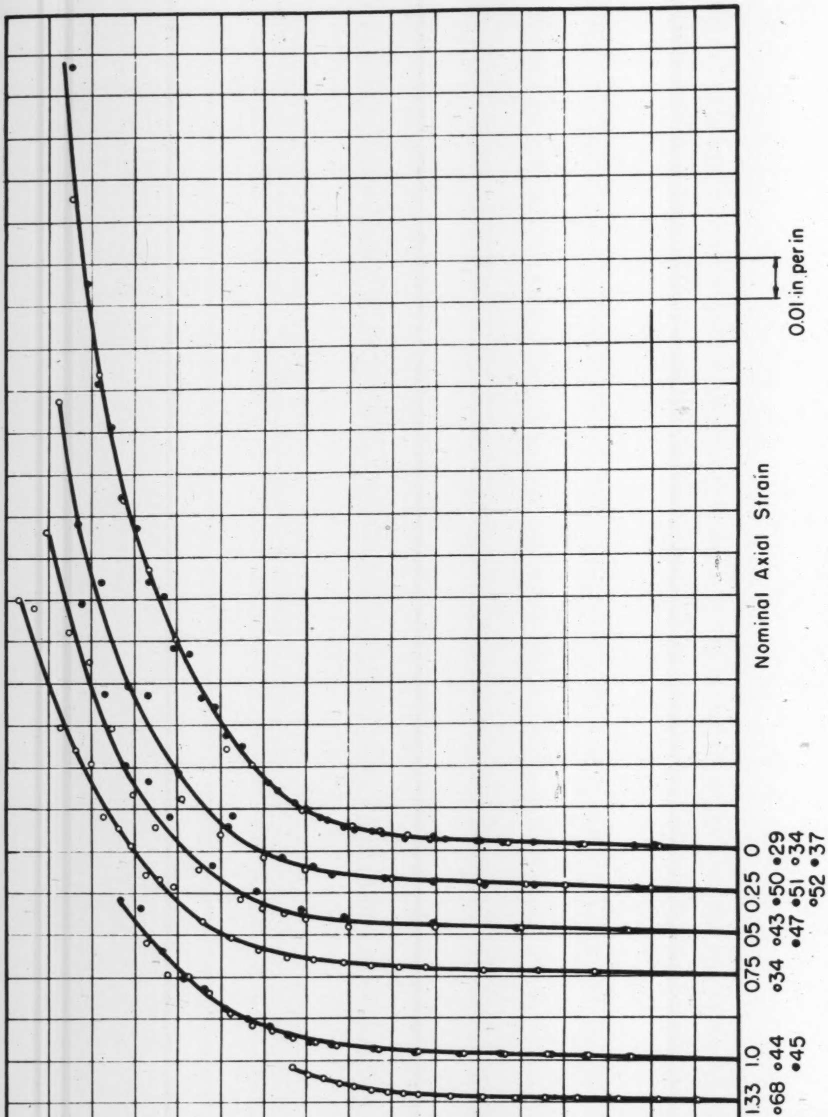

FIG. 3.—Nominal Axial Stress-Strain Diagram for Constant Stress Ratio Test.

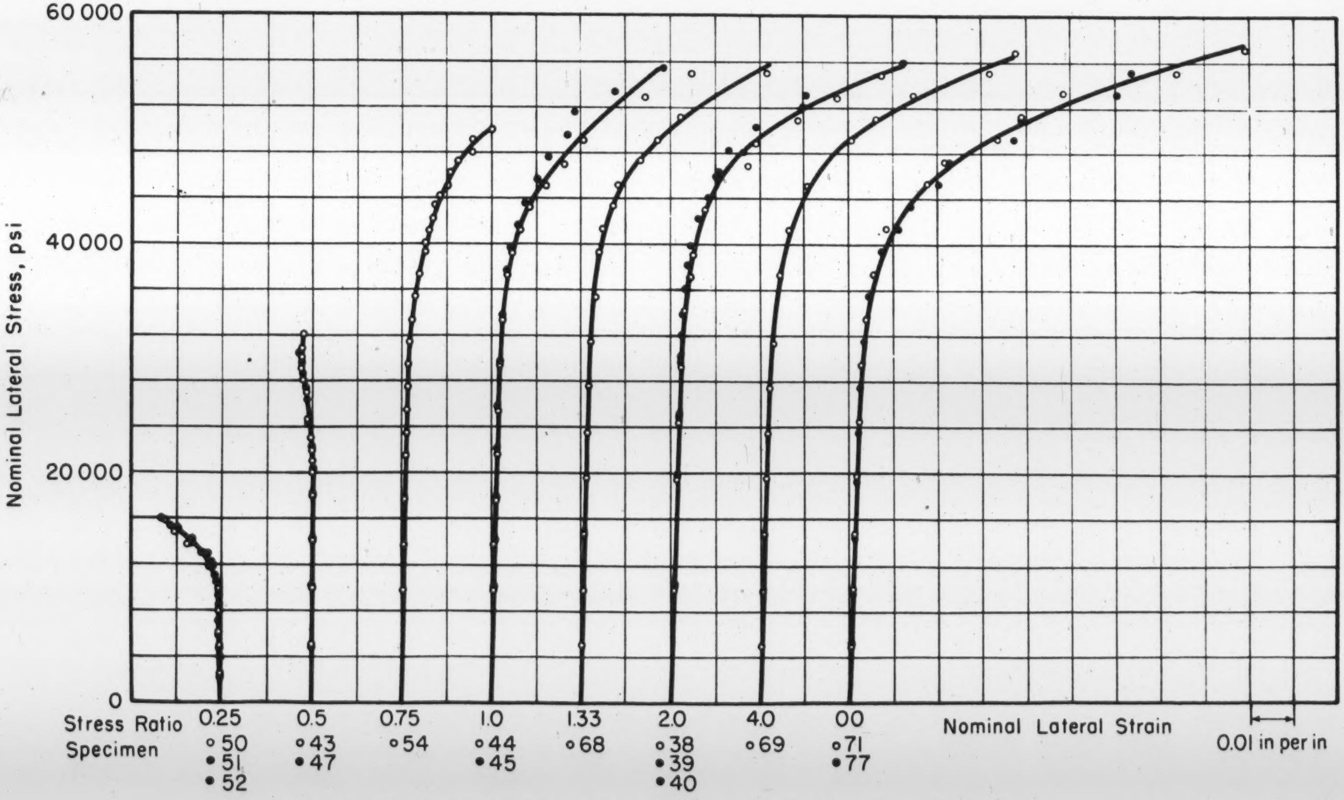

FIG. 4.—Nominal Lateral Stress-Strain Diagram for Constant Stress Ratio Test.

with the apparatus described by Marin, Faupel, Dutton, and Brossman (2). The ratio of the wall thickness to diameter of the specimen was 0.05, so that the biaxial stresses throughout the wall were essentially constant.

Testing Machine:

The testing machine used is shown in Fig. 2 and is described in detail by Marin, Ulrich, and Hughes (3). The axial load is applied to the specimen *S* by a lever *L*, vertical rod *R*, and hydraulic jack *J*, and is measured by a dynamometer *D*. The internal pressure to the specimen is applied through a valve *V* and pump unit and is measured by a gage *G*.

Method of Measuring Strains:

The elastic strains were measured by SR-4 electric strain gages placed both in the axial and lateral directions. A clip type gage, as shown in Fig. 2, was used to measure both the axial and lateral strain. The strain readings were recorded by an indicator *I* with the aid of a switch box *B*. Details of the methods of strain measurement used are given by Marin, Ulrich, and Hughes (3).

Method of Testing

The specimen is first assembled in the testing machine with the elastic strain gages and clip gages attached as shown in Fig. 2. The manner of load application used then depends upon the type of test being conducted. In all cases, the predetermined values of load are applied and values of the loads and strain readings are recorded.

CONSTANT STRESS RATIO TESTS

Plastic stress-strain relations for various constant values of the biaxial stress ratios were obtained to provide standard information regarding the influence of the principal stress ratio on the plastic stress-strain relations and the mechanical properties. In order to improve the isotropy of the material, it was suggested that the specimens be prestressed beyond the elastic limit prior to testing. The influencing of prestressing is described in a paper by Templin (4). For this purpose, two series of tests were conducted, one without prestraining and the other with prestraining to a strain value of 0.002 in. per in. in both the axial and lateral directions. All the test results on the series of tests with prestraining are not reported in the following, since it was found that the prestraining had negligible effect. For this reason, specimens were not prestrained initially in the remaining tests.

Conventional Stress-Stain Results:

The average conventional stress-strain curves for various principal stress ratios and for the axial and lateral directions are shown in Figs. 3 and 4. For all stress ratios at least two specimens were tested.

The equations used for calculating the nominal axial and lateral stresses in Figs. 3 and 4 were

$$\sigma_{1e} = \frac{pd^2 + 4P/\pi}{4t(d + t)} \quad \ldots\ldots\ldots (1)$$

$$\sigma_{2e} = \frac{pd}{2t}\left[\frac{1 + 2(t/d) + 2(t/d)^2}{1 + (t/d)}\right] \quad \ldots (2)$$

where:

p = the pressure,
P = the axial load,
d = the internal diameter of the specimen, and
t = the wall thickness.

Equation 2 is the lateral stress based on the Lame theory for a thick-walled cylinder, since for $t/d = 0.05$ a value of stress 5 per cent greater than the value considering the theory of the thin-walled tube is obtained.

The nominal strain values plotted in Figs. 3 and 4 were determined by the

SR-4 indicator readings. These readings were corrected for lateral sensitivity and the "combined stress effect" since the manufacturer's calibration constants supplied with the strain gages are applicable for steel or other materials with a Poisson's ratio of 0.285. The yield strength for uniaxial tension is given in Table I. This value is based upon an offset strain of 0.002 in. per in. For the combined stress tests, the yield stresses are determined from Figs. 3 and 4 and are based on an equivalent offset strain as determined by Marin, Ulrich, and Hughes (3). The values for these yield strengths for various principal stress ratios are listed in Table I.

TABLE I.—YIELD STRESSES FOR VARIOUS RATIOS OF BIAXIAL STRESSES.

Stress Ratio	Axial Yield Stress	Lateral Yield Stress	Stress Ratio	
$R = \frac{\sigma_2}{\sigma_1}$.... $= \frac{\tau_t}{\sigma_a}$....	σ_{ay} 10^4 psi	σ_{ty} 10^4 psi	$x = \frac{\sigma_{ay}}{\sigma_y}$	$y = \frac{\sigma_{ty}}{\sigma_y}$
0	3.57	...	1.00	0.00
0.25.........	3.95	1.04	1.11	0.29
0.5..........	3.86	1.66	1.08	0.47
0.75.........	4.02	3.16	1.13	0.89
1.0..........	3.53	3.60	0.99	1.01
1.33.........	3.00	3.85	0.84	1.08
2.0..........	1.74	3.91	0.49	1.09
4.0..........	1.08	3.77	0.30	1.06
∞...........	...	3.68	0.00	1.03

Plastic Stress-Strain Results:

The relation between the true stresses and strains for the entire range of stress and for the various principal stress ratios are given in Figs. 5 and 6. These stress-strain relations differ from the conventional diagrams since they consider the change in the gage length and change in cross-sectional dimensions with increase in load. The experimental curves shown in Figs. 5 and 6 are based on the average nominal stress-strain curves for at least two specimens as given in Figs. 3 and 4.

It is shown that the true axial and lateral strains in terms of the nominal axial and lateral strains e_1 and e_2 are

$$\left.\begin{aligned} \epsilon_1 &= \ln(1 + e_1) \\ \epsilon_2 &= \ln(1 + e_2) \end{aligned}\right\} \quad \text{.........(3)}$$

The value of the lateral nominal strain e_2 will be taken as the average strain value since the average stress values are used. To obtain the average lateral strain value, the lateral strain on the inside of the specimen can first be determined by assuming that the volume remains constant and by using the measured lateral strain on the outside of the specimen (e_{2o}) and the axial strain (e_1). Then the nominal strain on the inside of the

TABLE II.—NOMINAL ULTIMATE STRESSES FOR VARIOUS BIAXIAL STRESS RATIOS.

Stress Ratio	Specimen	Axial Ultimate Stress	Lateral Ultimate Stress	Stress Ratio	
$R = \frac{\sigma_2}{\sigma_1}$... $= \frac{\sigma_t}{\sigma_a}$...		σ_{au} 10^4 psi	σ_{tu} 10^4 psi	$x = \frac{\sigma_{au}}{\sigma_u}$	$y = \frac{\sigma_{tu}}{\sigma_u}$
0..........	34	6.18	...		
	29	6.41	...		
	37	6.30	...		
	Average	6.30	...	1.00	0.00
0.25.......	50	6.32	1.58		
	52	6.41	1.60		
	51	6.14	1.53		
	Average	6.29	1.57	1.00	0.25
0.5........	41	6.43	3.21		
	43	6.42	3.21		
	47	6.30	3.15		
	Average	6.38	3.19	1.01	0.51
0.75.......	54	6.68	5.01		
	Average	6.68	5.01	1.06	0.80
1.0........	44	5.70	5.70		
	45	5.75	5.75		
	Average	5.72	5.72	0.91	0.91
1.33.......	67	4.04	5.39		
	68	4.14	5.51		
	Average	4.09	5.45	0.65	0.87
2.0........	38	2.84	5.68		
	39	2.72	5.45		
	40	2.81	5.62		
	Average	2.79	5.58	0.44	0.89
4.0........	69	1.43	5.71		
	Average	1.43	5.71	0.23	0.91
∞.........	71	...	5.72		
	77	...	5.53		
	Average	...	5.63	0	0.89

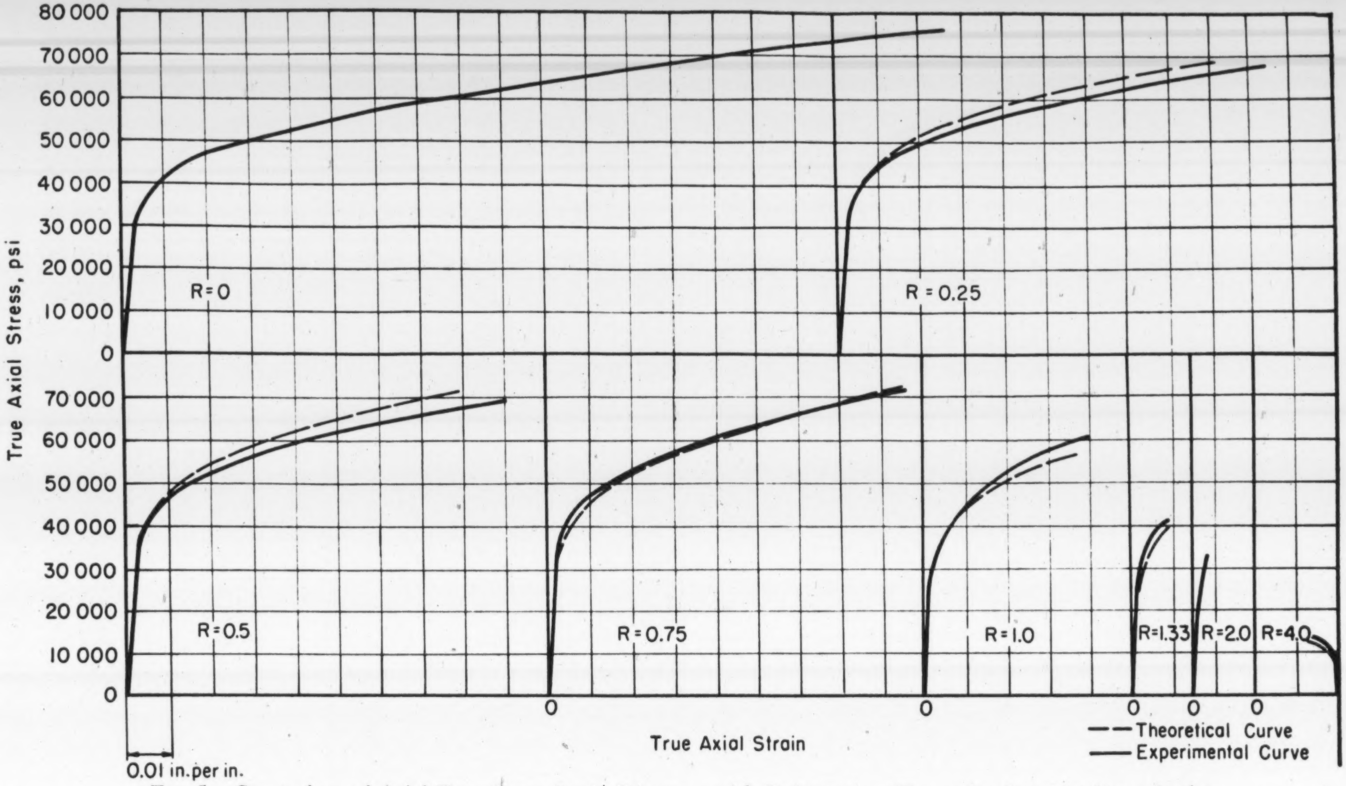

FIG. 5.—Comparison of Axial True Stress-Strain Diagrams with Deformation Theory for Constant Stress Ratios.

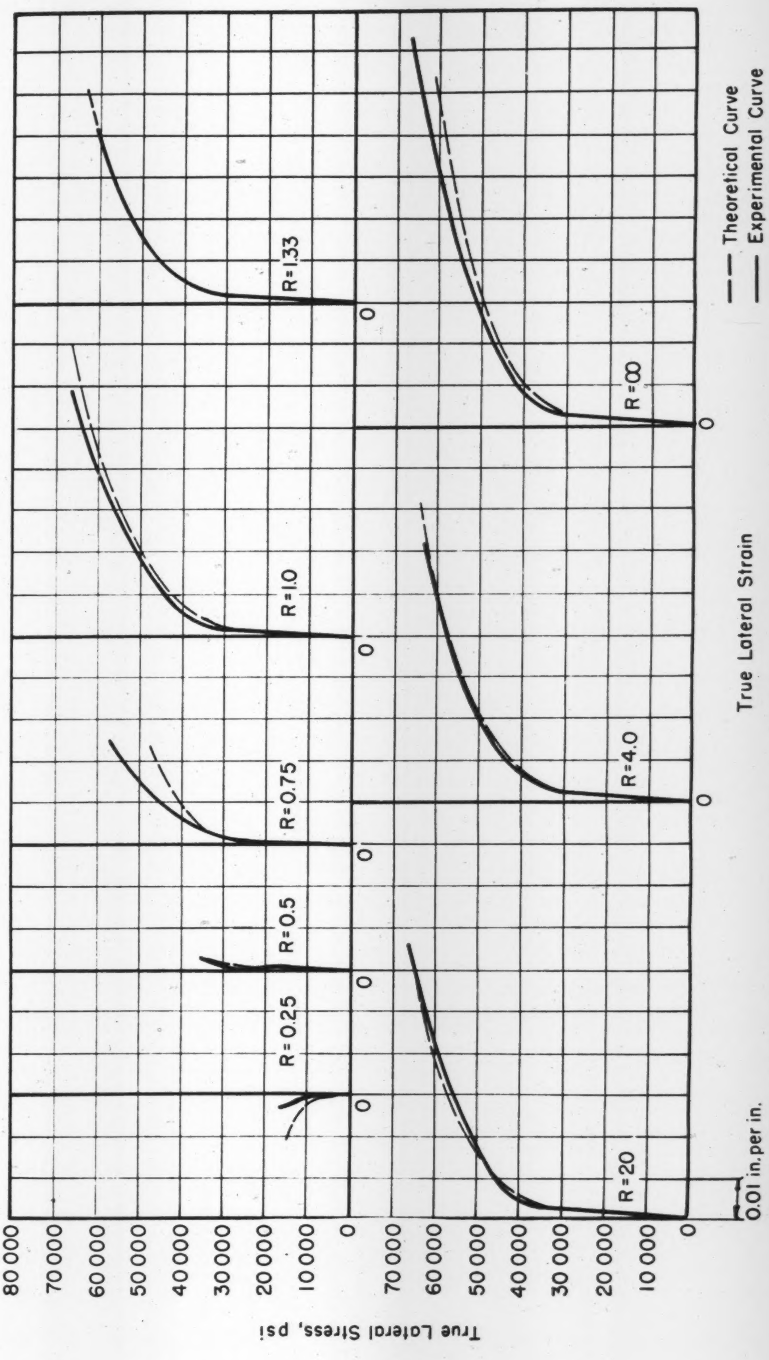

FIG. 6.—Comparison of Lateral True Stress-Strain Diagrams with Deformation Theory for Constant Stress Ratios.

specimen wall becomes

$$e_{2i} = \left(\frac{d + 2t}{d}\right)^2 e_{2o} + \frac{1}{2}\left[\frac{(d + 2t)^2}{d^2} - 1\right] e_1 \quad (a)$$

TABLE III—TRUE FRACTURE STRESSES FOR VARIOUS RATIOS OF BIAXIAL STRESSES.

Stress Ratio	Axial Fracture Stress	Lateral Fracture Stress	Stress Ratio	
$R = \frac{\sigma_2}{\sigma_1}$ ..... $= \frac{\sigma_t}{\sigma_a}$	σ_{au} 10^4 psi	σ_{tu} 10^4 psi	$x = \frac{\sigma_{au}}{\sigma_u}$	$y = \frac{\sigma_{tu}}{\sigma_u}$
0.00	7.65	0	1.0	0.00
0.25	6.90	1.71	0.90	0.22
0.50	6.90	3.51	0.90	0.46
0.75	7.19	5.66	0.94	0.76
1.00	6.14	6.66	0.80	0.87
1.33	4.15	6.03	0.54	0.79
2.00	3.07	6.43	0.40	0.84
4.00	1.41	6.40	0.18	0.84
∞	0	6.74	0.00	0.88

TABLE IV.—DUCTILITY VALUES FOR VARIOUS BIAXIAL STRESS RATIOS.

Stress Ratio	True Axial Strain	True Lateral Strain	Significant Strain
$R = \frac{\sigma_t}{\sigma_a}$ .... $= \frac{\sigma_2}{\sigma_1}$	ϵ_a 10^{-2} in. per in.	ϵ_t 10^{-2} in. per in.	$\bar{\epsilon}$ 10^{-2} in. per in.
0	16.07	−6.16	15.25
0.25	10.20	−1.27	10.96
0.5	8.71	−0.13	9.63
0.75	8.43	1.75	10.54
1.0	3.86	5.16	9.06
1.33	0.87	3.72	4.79
2.0	0.24	5.32	7.13
4.0	−0.65	5.6	6.2
∞	−1.71	8.58	9.25

Then the average lateral nominal strain is

$$e_2 = \frac{e_{2i} + e_{2o}}{2} = \frac{1}{2}\left[\frac{(d + 2t)^2}{d^2} + 1\right] e_{2o} + \frac{1}{4}\left[\frac{(d + 2t)^2}{d^2} - 1\right] e_1 \ldots\ldots (4)$$

That is, the average nominal strain e_2 is defined by Eq 4 in terms of the measured axial strain e_1 and the lateral strain e_{2o} on the outside of the specimen.

The true axial and lateral stresses can be obtained by using the stress formulas for a thin-walled tube provided the initial diameter d and wall thickness t are replaced by their actual values d_p and t_p. That is, the true stress equations for the plastic range are

$$\sigma_1 = \frac{pd_p^2 + 4P/\pi}{4t_p(d_p + t_p)} \ldots\ldots\ldots (5)$$

$$\sigma_2 = \frac{pd_p}{2t_p} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

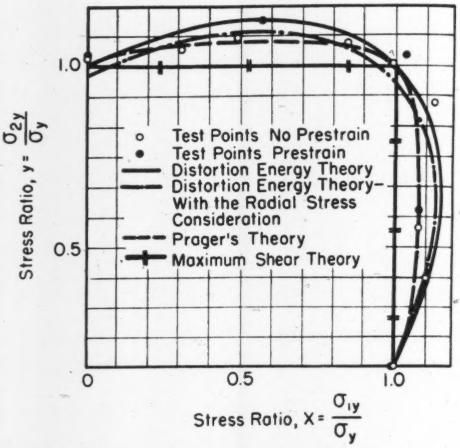

FIG. 7.—Comparison of Yield Strengths with Theories of Failure.

In an earlier paper (2), values of d_p and t_p are shown to be

$$t_p = \frac{t}{1 + e_1 + e_2} \ldots\ldots\ldots (7)$$

$$d_p = (d + 2t)(1 + e_2) - 2t_p \ldots\ldots (8)$$

The true stress-strain diagrams given in Figs. 5 and 6 are based on values of stress and strain as defined by Eqs 3, 4, 5, and 6.

From the data obtained from Figs. 3 and 4, the nominal fracture strengths for various biaxial stress ratios were determined. These values are listed in Table II. The true fracture stresses for various biaxial stress ratios, as determined from Figs. 5 and 6, are listed in Table III. The nominal and true strains at fracture for various biaxial stress ratios, as given in Table IV, provide measures of the ductility under combined stresses.

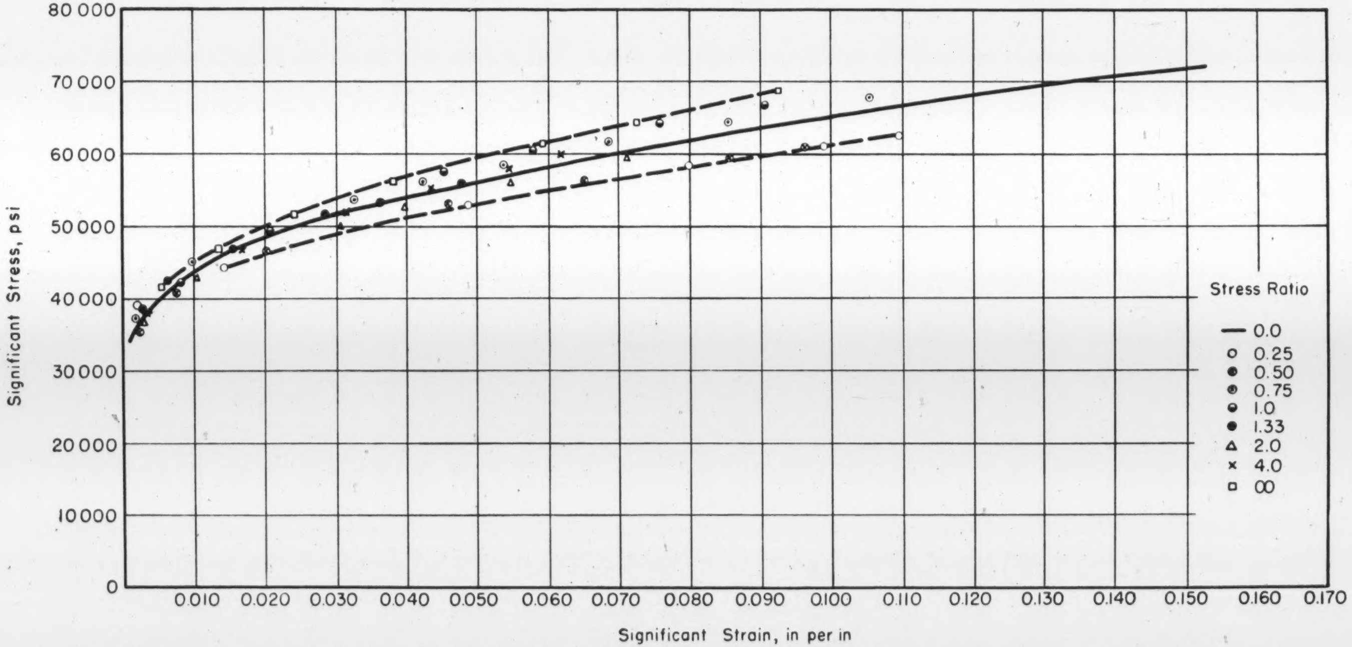

FIG. 8.—Comparison of Significant Stress-Strain Relations with the Uniaxial True Stress-Strain Values for Constant Stress Ratio Tests.

Analysis and Discussion:

A comparison between the experimental and theoretical values of the yield strengths for various biaxial stress ratios is shown in Fig. 7 for prestressed specimens and for specimens that were not prestressed. Figure 7 shows that the influence of prestressing in the axial and lateral directions is negligible. The theories shown in Fig. 7 include the well-known distortion energy and shear theories and a semi-empirical theory by Prager (5) based on the second and third stress invariants. A comparison of the theoretical values and test results in Fig. 7 shows that the yield strengths can best be defined by the distortion energy theory when corrected for the radial stress.

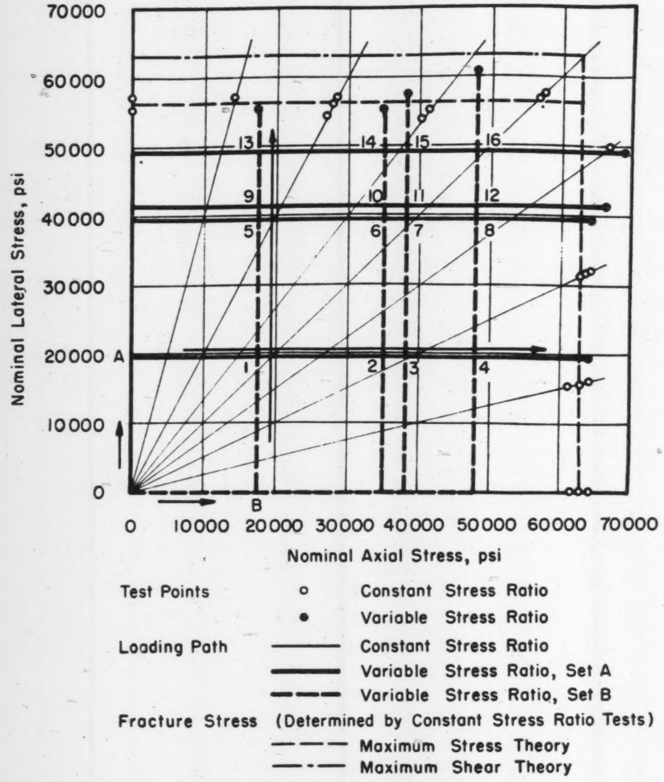

FIG. 9.—Comparison of Nominal Fracture Stresses.

Plastic stress-strain relations are compared with the theory by plotting the variation between the significant stress and strain (2) and comparing with the true uniaxial stress-strain relations (Fig. 8). The values of the significant stress ($\bar{\sigma}$) and strain ($\bar{\epsilon}$) were computed by the equations

$$\bar{\sigma} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]} \quad (9)$$

$$\bar{\epsilon} = \sqrt{\frac{4}{3}\left[\epsilon_1^2 + \epsilon_1\epsilon_2 + \epsilon_2^2\right]} \quad \ldots\ldots (10)$$

In calculating the significant stress by Eq 9 $\sigma_3 = -\frac{p}{2}$ the average σ_3 stress is used. The agreement between the stress-strain relations in Fig. 8 and the theoretically predicted value as given by the simple tension relation is considered good when the anisotropy of the material is considered. For constant stress ratios, the deformation and flow type theories are identical so that the comparisons shown in Fig. 8 refer to both theories.

A comparison of the actual true stress-strain relations and the values predicted by theory for each principal stress ratio is shown in Figs. 5 and 6. The determination of the theoretical stress and strain is explained in Appendix I of an earlier paper (3). Figures 5 and 6 show that for constant stress ratios there is good agreement between the test results and theory.

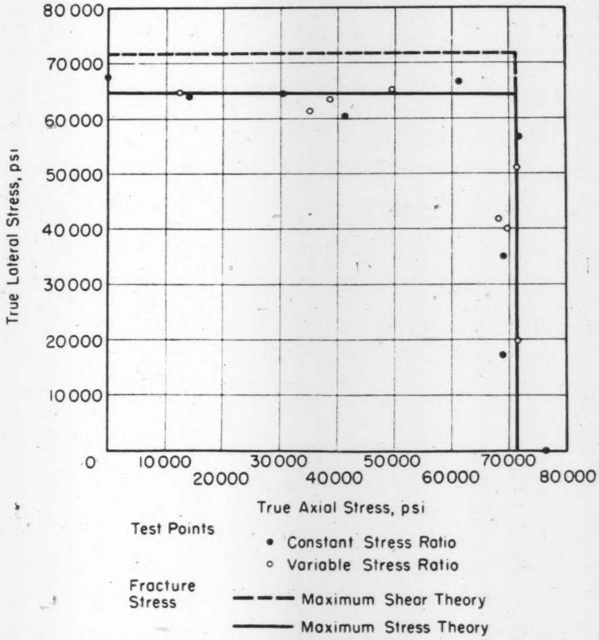

FIG. 10.—Comparison of True Fracture Stresses with Theory of Failure for Constant and Variable Stress Ratio Tests.

Nominal biaxial ultimate strengths, as given in Table II, are compared in Fig. 9 with values predicted by the maximum stress and maximum shear theories of failure. The results show that the maximum stress theory approximately agrees with the test results.

True biaxial fracture strengths, as given in Table III, are compared with the maximum shear and maximum stress theories in Fig. 10. As for the nominal ultimate strengths, Fig. 10 shows that the maximum stress theory approximately agrees with the test results. The biaxial fracture strengths for specimens with and without prestraining were found to be about the same, indicating that prestraining had little effect upon the isotropy of the material.

Ductility values based upon both the nominal and true principal strains at fracture are given in Table IV for the various biaxial stress ratios tested. Table IV shows that the ductility decreases with increase in biaxiality of the stresses. The anisotropy of the material somewhat obscures the influence of biaxiality upon the ductility. The anisotropy of the material is also indicated by the difference in values of the strength coefficient k and strain exponent n for uniaxial stressing of the material in the axial and lateral directions (Table V). The constants k and n are the values in the uniaxial true stress-strain relation $\sigma = k\epsilon^n$ which represents a straight line relation between the true stress σ and true plastic strain $\bar{\epsilon}$ on a log-log plot.

TABLE V.—TRUE STRESS-STRAIN CONSTANTS FOR UNIAXIAL TENSION.

Loading Direction	Specimen	Nominal Ultimate Stress, psi	True Fracture Stress, psi	True Ductility, 10^{2} in. per in.	Constant	
					K, psi	n
Axial........	34	61 800	74 600	0.145		
$R = 0$.......	29	64 100	78 800	0.172		
	37	63 000	76 100	0.184		
Average...		63 000	76 500	0.161	97 700	0.177
Lateral......	71	57 200	68 700	0.914		
$R = \infty$......	77	55 300	66 000	0.823		
Average...	...	56 300	67 400	0.858	102 000	0.175

Another measure of ductility may be taken as the value of the significant strain $\bar{\epsilon}$ at fracture as calculated from Eq 10. The variation of the significant strains at fracture with principal stress ratio is shown in Fig. 11.

In order to show whether the ratios of the principal shear stresses to the principal shear strains are equal as assumed by the deformation theory, values of μ and ν were computed (6). The theory requires that there be a straight line relation between μ and ν but the test data was found to depart appreciably from this straight line relation.

VARIABLE STRESS RATIO TESTS WITHOUT UNLOADING

The constant stress ratio tests discussed in the foregoing cannot determine whether the deformation or flow theory agrees best with the test results, since for constant stress ratios the two theories coincide. For this reason, variable stress ratio tests were conducted by applying a stress in one principal direction only and then superimposing a stress to fracture in the other principal stress direction. The test procedure that was used for these tests was essentially the same as for the constant stress ratio tests. Two sets of variable stress ratio tests were conducted: Set A tests in which a uniaxial tensile stress in the lateral direction was first applied by using a special device to remove the axial loading on the specimen produced by the internal pressure and Set B tests in which a uniaxial axial tensile stress was first applied. In both kinds of tests, specimens were initially subjected to various magnitudes of uniaxial stresses before the subsequent loading in the other direction.

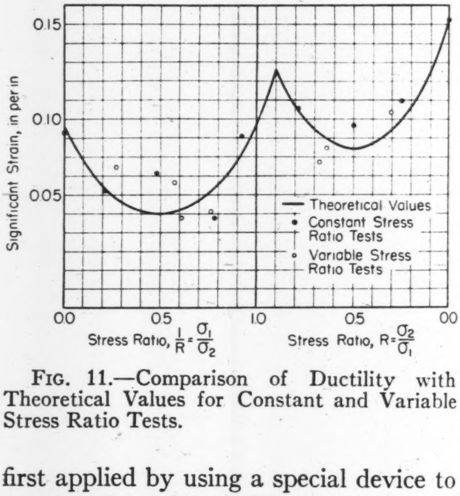

FIG. 11.—Comparison of Ductility with Theoretical Values for Constant and Variable Stress Ratio Tests.

Results and Analysis:

The nominal stress-strain relations for one test are shown in Fig. 12. The manner of loading and the amount of initial uniaxial stress and strain are shown in the figure, and the stage of loading is

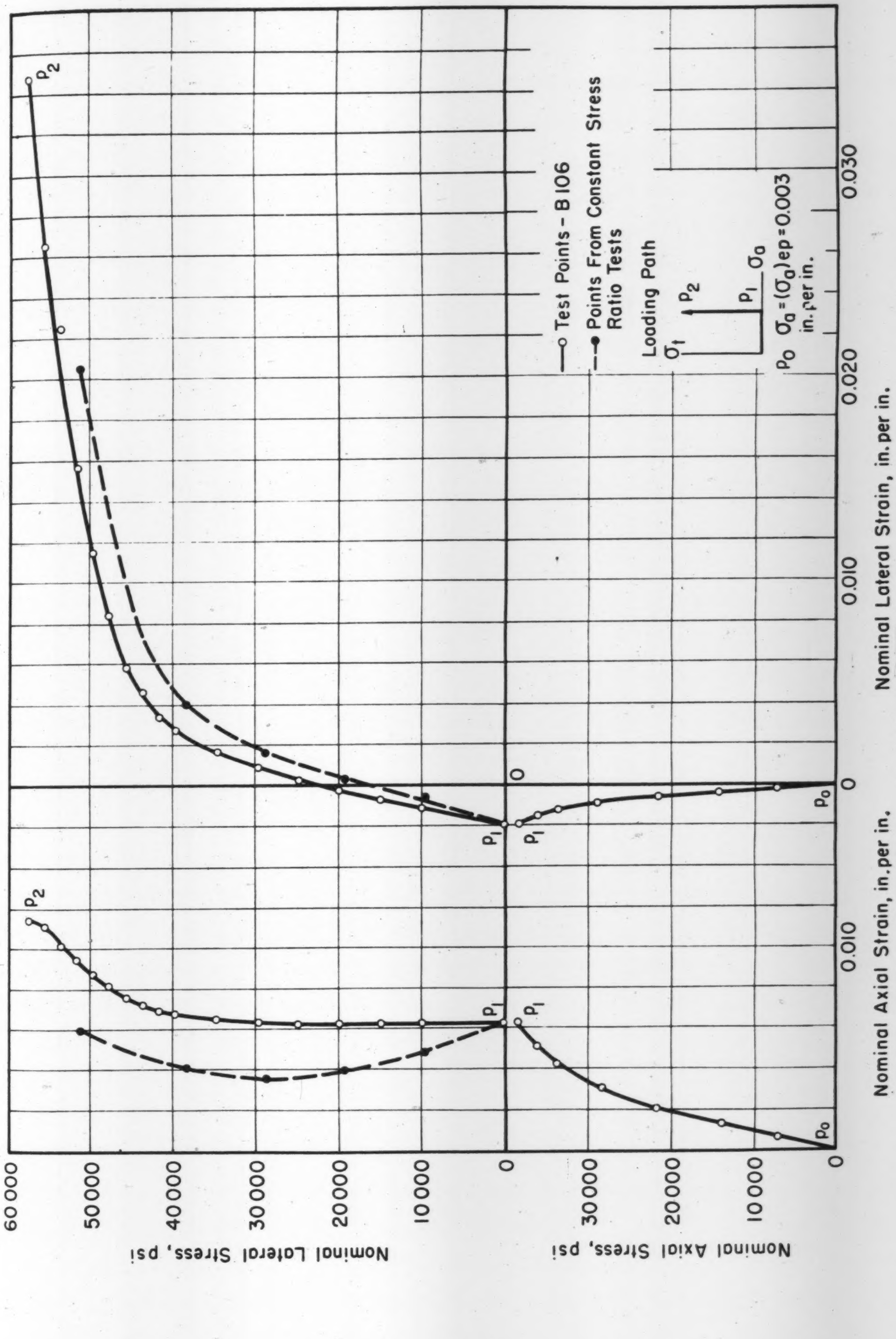

FIG. 12.—Nominal Stress-Strain Relations for Variable Stress Ratio Test—Set B, No. 3.

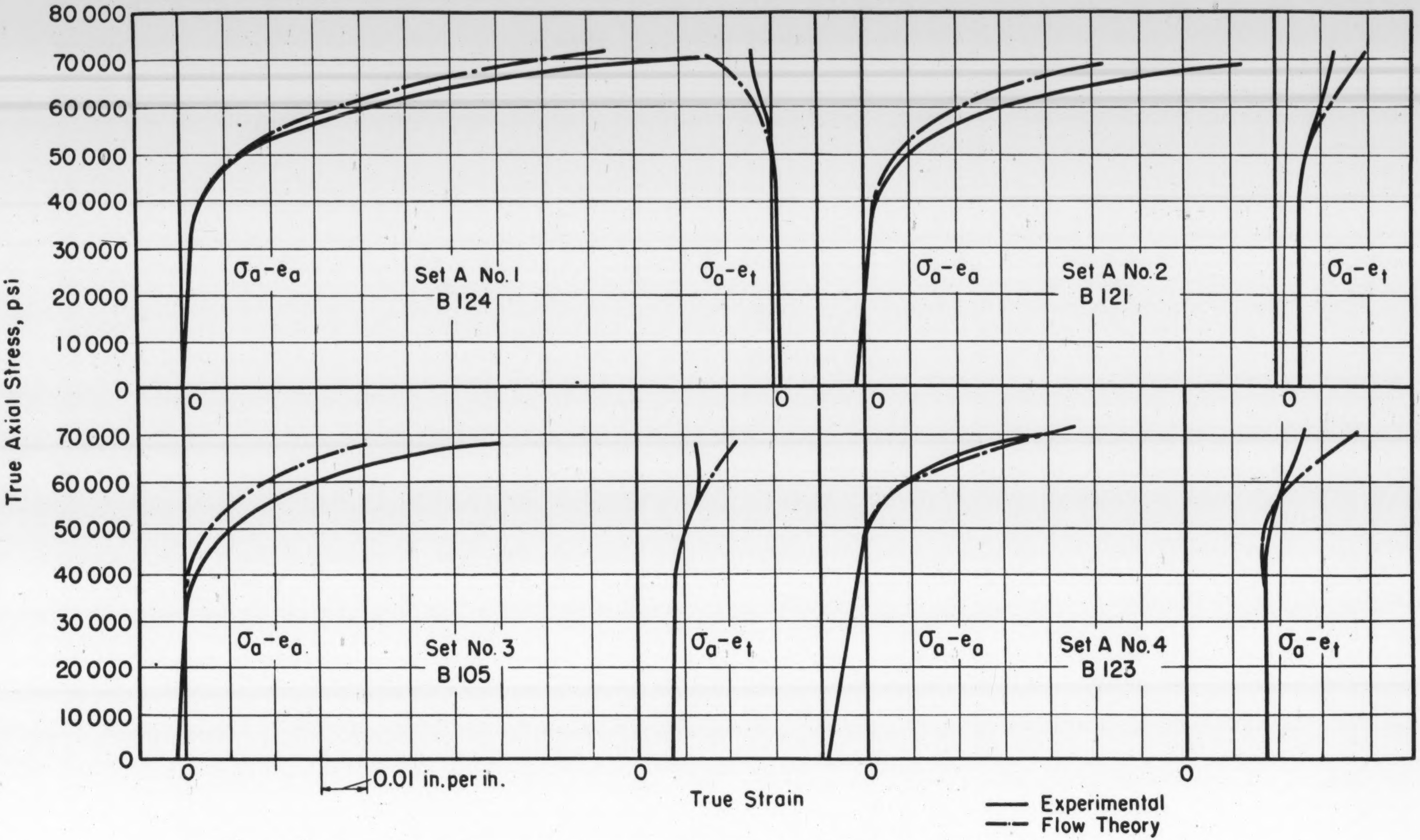

FIG. 13.—Comparison of True Stress-Strain Diagrams with Plasticity Theories for Variable Stress Ratio Tests—Set A.

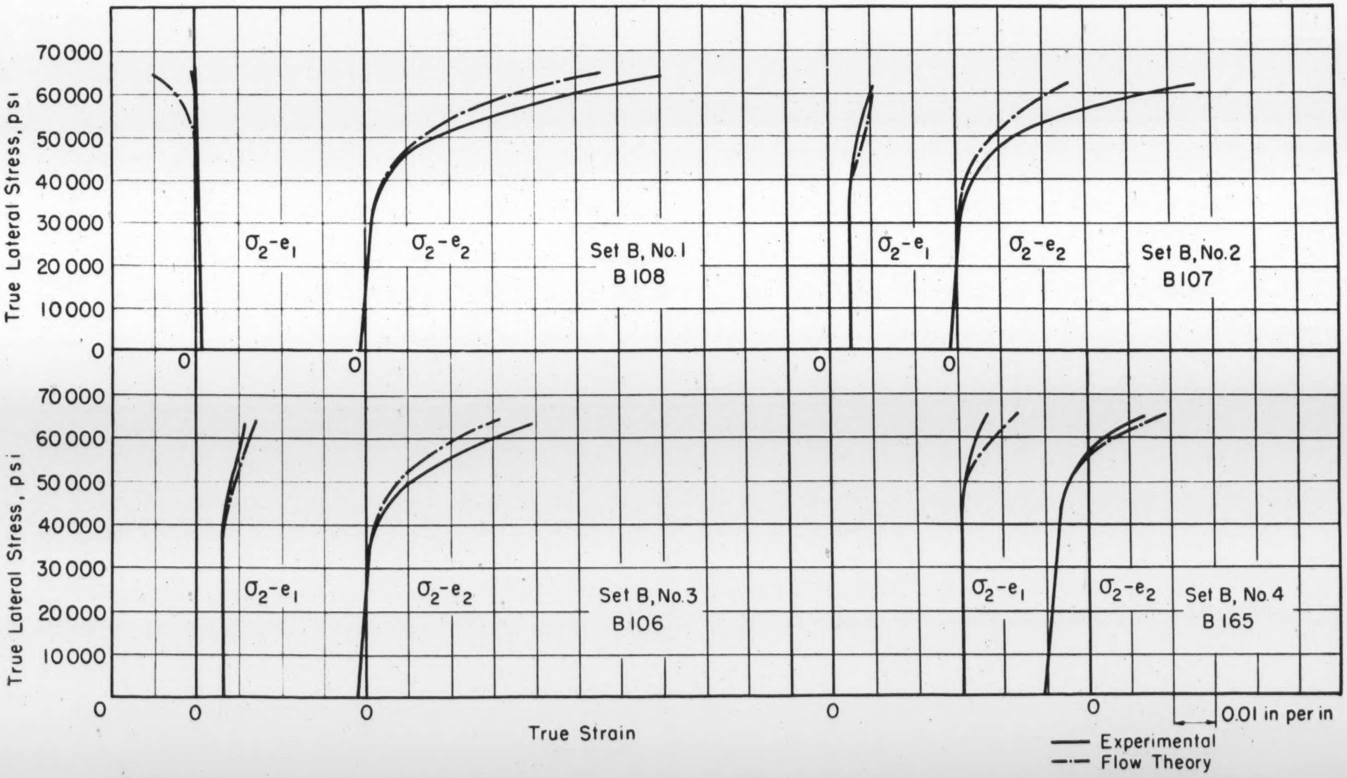

FIG. 14.—Comparison of True Stress-Strain Diagrams with Plasticity Theories for Variable Stress Ratio Tests—Set B.

indicated by points labeled P_0, P_1, P_2. In Fig. 12, the stress-strain diagrams obtained, based on the constant stress ratio tests are shown to indicate the influence of the initial stressing.

A comparison of the actual true plastic stress-strain relations with the theoretical values as given by the flow theory for both Set A and Set B tests is shown in Figs. 13 and 14, respectively. The determination of the theoretical values based on the uniaxial tension test results is explained by Marin, Ulrich, and Hughes (3). Figure 13 and 14 show that the flow theory agrees approximately with the test results.

TABLE VI.—COMPARISON OF TRUE STRAINS USING DIFFERENT LOADING PATHS.

Point	True Axial Strain 10^{-3} in. per in.				True Lateral Strain 10^{-3} in. per in.			
	Set A (initial σ_t)	Set B (initial σ_a)	Difference		Set A (initial σ_t)	Set B (initial σ_a)	Difference	
			in. per in.	per cent			in. per in.	per cent
1	1.20	1.25	0.05×10^{-3}	4.0	1.40	1.30	-0.10×10^{-3}	−7.7
2	3.25	5.15	1.90	36.9	1.00	0.30	−0.70	−23.3
3	4.30	6.30	2.00	31.7	0.95	−0.10	−1.05	105.0
4	13.50	30.50	17.00	55.7	0.35	−0.84	−1.19	141.6
5	0.00	1.00	1.00	100.0	5.20	5.40	0.20	3.7
6	1.85	5.11	3.26	63.8	5.20	4.60	−0.60	−13
7	2.75	6.6	3.85	58.3	5.40	3.10	−2.30	−74.2
8	9.25	30.60	20.35	66.5	6.60	−6.50	−13.10	200
9	−0.60	9.50	10.10	106.3	7.70	6.80	−0.70	−10.3
10	1.05	5.40	4.35	80.6	7.80	5.80	−2.0	−34.5
11	2.10	6.90	4.80	69.6	8.10	4.05	−4.05	−100
12	9.90	30.70	20.8	67.8	10.90	−6.10	−17.0	278.6
13	−5.60	8.00	13.6	170	17.70	18.60	0.90	4.8
14	−2.60	7.20	9.8	136.1	17.50	16.10	−1.40	−8.7
15	−2.00	8.70	10.7	123	17.50	12.00	−5.50	−45.8
16	0.40	31.50	31.1	98.7	18.80	−3.60	−22.40	622.2

Figure 9 compares the nominal fracture strengths as given by the foregoing variable stress tests with the values obtained by the constant stress ratio tests. The agreement between the nominal fracture strength values as given by the constant and variable stress ratio tests indicates that the path of loading has some influence on the nominal fracture strengths. Figure 10 gives a comparison of the true fracture strengths as determined by the foregoing variable stress ratio tests and by the constant stress ratio tests. The data show that there is good agreement, as far as fracture strength values are concerned, between these two types of loading. Furthermore, the true fracture strengths for the variable stress ratio tests agree well with the maximum stress theory. These results also show that the path of loading has little effect on the true fracture strength.

A comparison of the ductility values as determined by the variable stress ratio tests and the theoretical values is shown in Fig. 11. The same general trend in variation of significant strain with principal stress ratio is found as with the constant stress ratio tests.

The foregoing variable stress ratio tests can also be used to distinguish between the deformation or slip type theory and the flow type theory. In order to make the foregoing distinctions, the loading paths used in the tests will first be summarized as indicated in Fig. 9. In Fig. 9, one set of tests, designated as Set A, corresponds to loading in the transverse direction to a stress $\sigma_t = \frac{\sigma_y}{2}$ (for example, as represented by point A) and then loading to points 1, 2, 3 and 4 in the axial direction. Another set of tests, designated as Set B, corresponds to loading, for example, in the axial direction to a stress $\sigma_a = \frac{\sigma_y}{2}$, as represented by point B, and then loading to points 1,

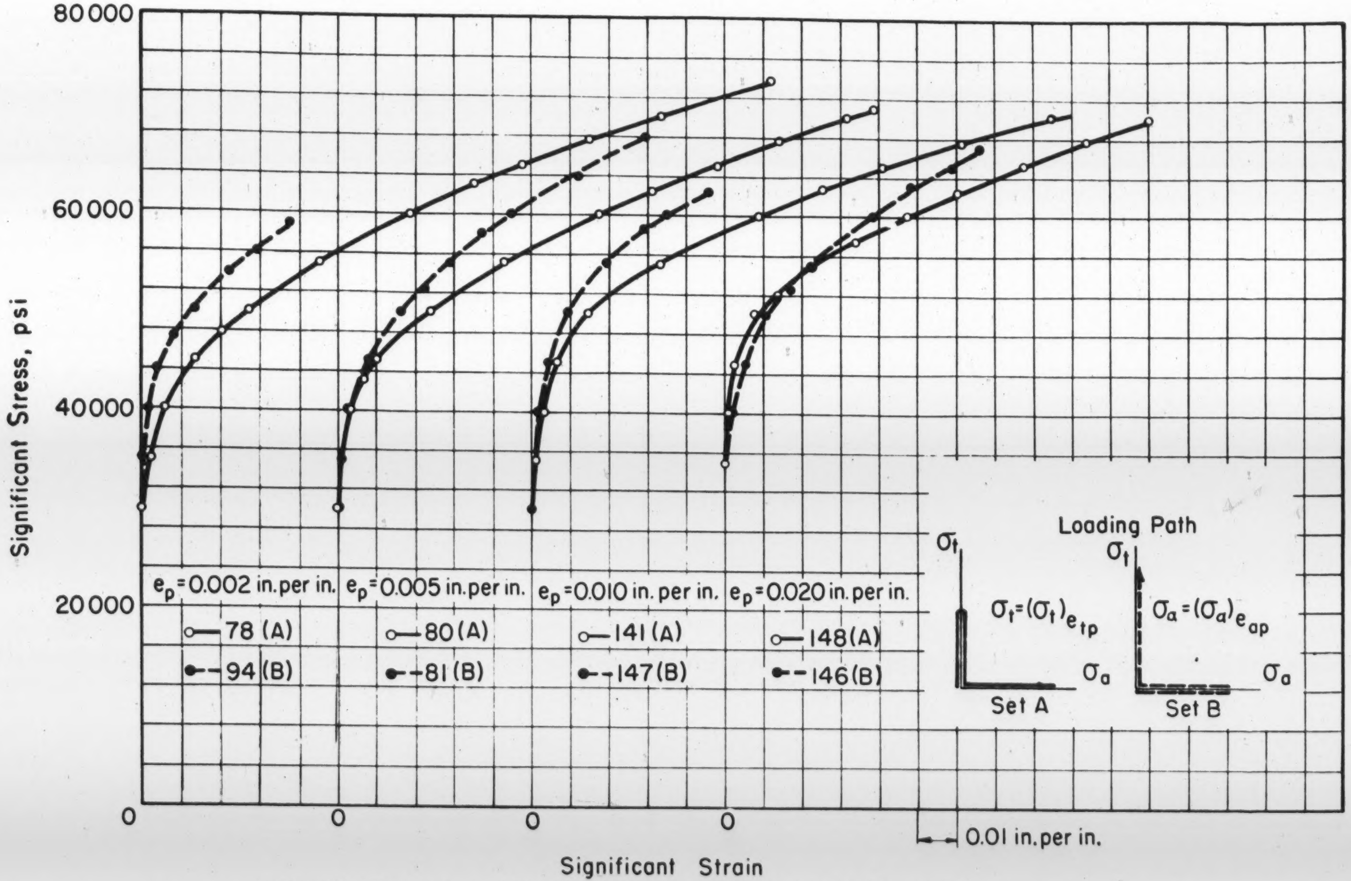

FIG. 15.—Comparison of Significant Stress-Strain Relations for Special Test—Type III.

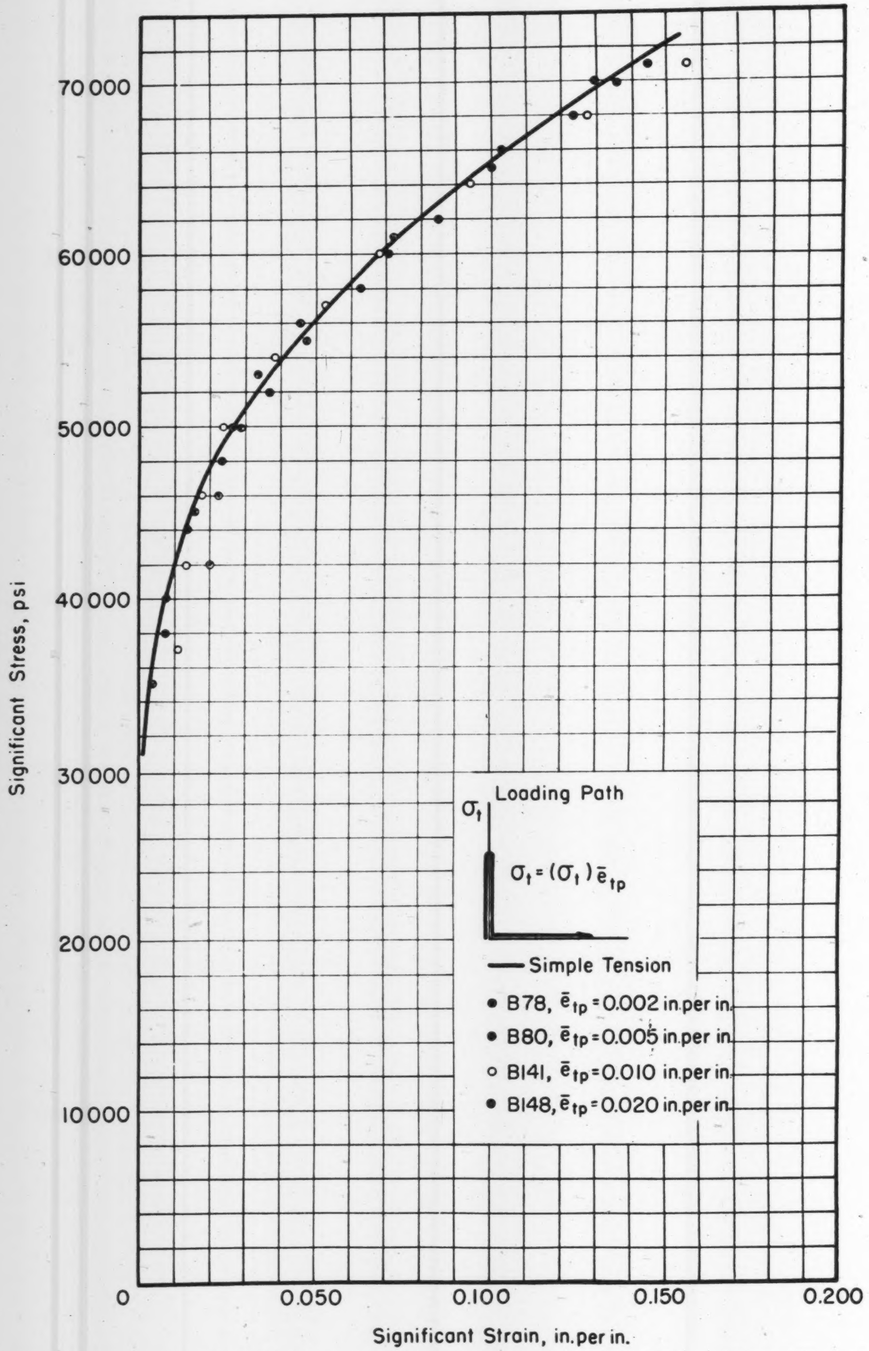

FIG. 16.—Comparison of Significant Stress-Strain Relations for Special Tests—Type III, Series A.

5, 9 and 13 in the transverse direction. According to the deformation and slip type theories, the axial and transverse strains corresponding to point 1 are the same, regardless of whether the loading path was *OA*1 or *OB*1. The first line in Table VI shows the strains in the axial and transverse directions for each path of loading and the percentage difference in these strains. Table VI also shows the percentage difference for points 2 to 16. The percentage difference in strains for the two different paths of loading lends support to the flow type theory rather than the deformation or slip theories. This conclusion appears correct since the large per cent differences in strains given in Table VI for each of the points 1 to 16 in Fig. 9 cannot be explained by anisotropy.

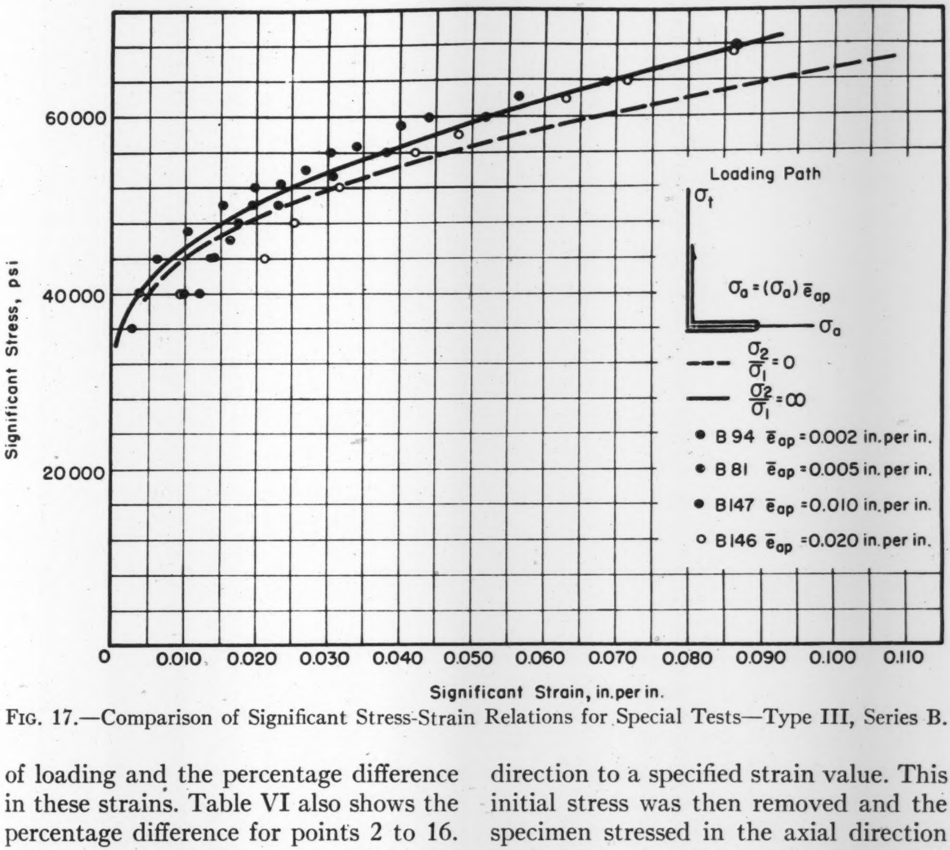

FIG. 17.—Comparison of Significant Stress-Strain Relations for Special Tests—Type III, Series B.

SPECIAL UNLOADING TESTS

It is assumed in the isotropic linear flow theories that initial prestraining will not produce anisotropy. In other words, it is assumed that isotropic yielding occurs. To determine the validity of this assumption a test was made in which a specimen was stressed first in the lateral direction to a specified strain value. This initial stress was then removed and the specimen stressed in the axial direction to fracture. Another specimen was initially stressed to the same initial specified strain as the first, but in the axial direction. The stress was then removed and stressing was applied in the lateral direction to fracture. If the assumption of isotropic yielding is valid, the significant stress-strain curves for each of the foregoing tests should coincide.

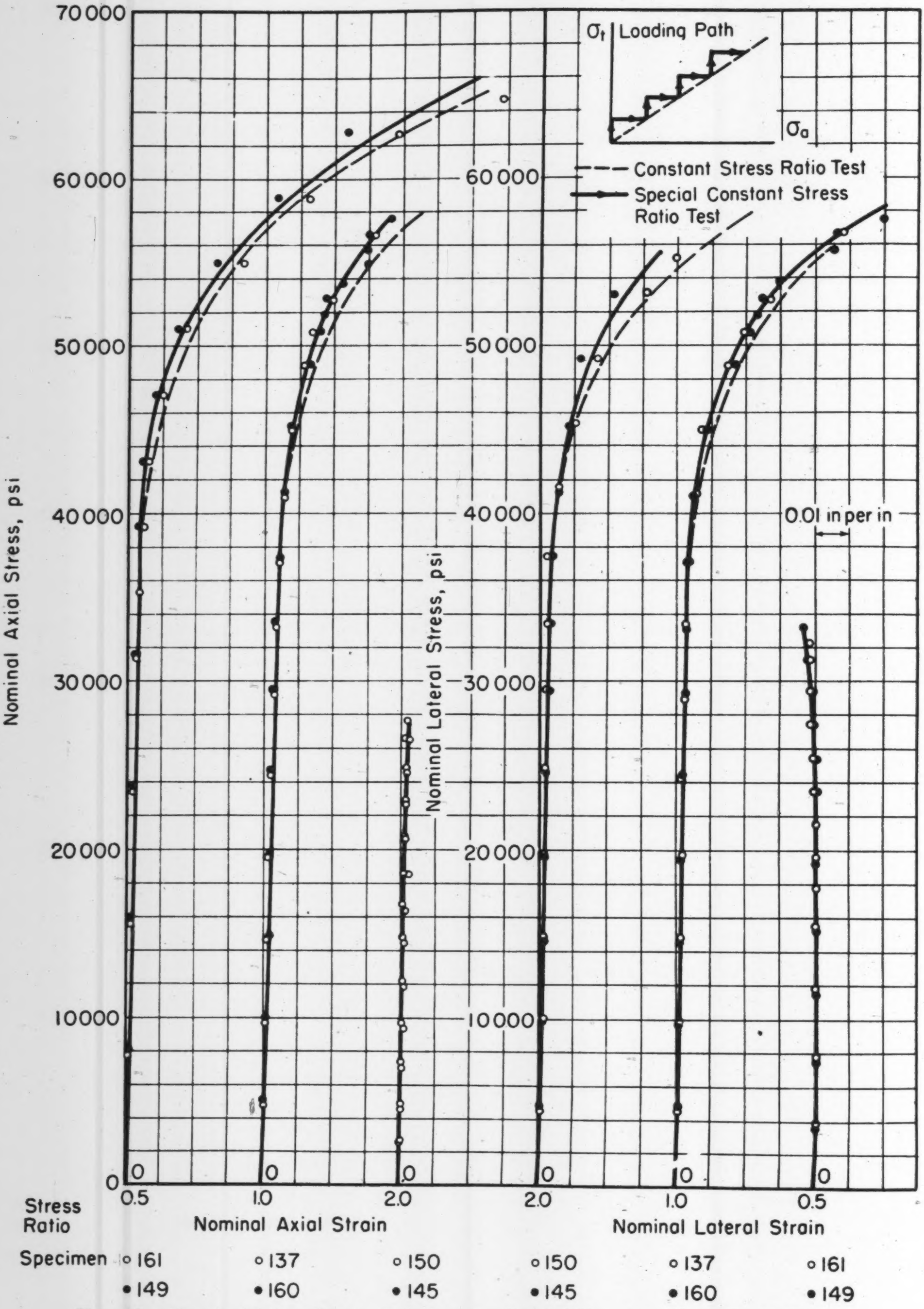

FIG. 18.—Nominal Stress-Strain Relations for Special Constant Stress Ratio Tests.

Results and Analysis:

Tests were made as described above for four initial strains of 0.002, 0.004, 0.010 and 0.020 in. per in. The nominal and true stress-strain relations for each series of tests were obtained. Based on these data, Fig. 15 gives a comparison of the significant stress-strain curves corresponding to each of the initial strain values of 0.002, 0.004, 0.010 and 0.020 in. per in. A comparison between the curves for the four graphs indicates that the assumption of isotropic yielding does not appear to be valid. However, the comparison of the curves in Fig. 15 is not conclusive since the material in the specimens was not initially isotropic. In order to eliminate the influence of the initial anisotropy, Figs. 16 and 17 were prepared. Fig. 16 shows a comparison of the significant stress-strain relations for Series A tests with the tensile stress-strain relation in the axial direction. The agreement in Fig. 16 between the test points and the tensile stress-strain diagram is good. In Fig.17, the test results for Series B tests in which the final stresses are applied in the lateral direction are shown. The variation in test points shown in Fig. 17 is on the order of magnitude of the difference between the lateral and axial uniaxial tension stress-strain relation. This would indicate that the assumption of isotropic yielding is satisfactory in so far as these tests are concerned.

SPECIAL CONSTANT STRESS RATIO TESTS

Special constant stress ratio tests were conducted as indicated by the loading path shown in Fig. 18. For example in Fig. 18 the stress ratio R or ratio of the lateral to axial stress is maintained approximately constant up to fracture. Unlike the usual constant stress ratio tests, however, the load is applied in steps as indicated in Fig. 18. That is, the stress is first applied in the lateral direction to a specific amount. The lateral stress is then kept constant and the stress is applied in the axial direction to an amount such that the principal stress ratio equals the value desired. Lateral and axial stresses are then applied successively so that at the end of each axial load application the principal stress ratio is the same.

Results and Analysis:

Figure 18 shows the nominal stress-strain relations for a principal stress ratio $R = \sigma_2/\sigma_1 = 0.5, 1.0,$ and 2.0. For stress ratio 0.5 increments of stress used were $\sigma_a = 4000$ and $\sigma_t = 2000$ psi; for stress ratio 1.0 increments of stress of 2000 psi were used for both directions. For the stress ratio 2.0 the increment of stress for σ_a was 2000 psi and for σ_t it was 4000 psi. In Fig. 18, the stress-strain relations for the constant stress ratio tests are also given. A comparison of the special constant stress ratio tests and the constant stress ratio tests indicates that the step loading has little influence on the stress-strain diagrams.

Figure 19 gives a comparison between the true stress-strain relations as obtained by the foregoing special step tests as found by the constant stress ratio tests and as defined by the flow and deformation theories. The curves indicate that the true stress-strain relations are independent of the path of loading. However, the results obtained cannot distinguish between the deformation and flow theories.

VARIABLE STRESS RATIO TESTS TO DISTINGUISH BETWEEN LOADING CRITERA

To determine whether the maximum shear criterion is more suitable for defining plastic stress-strain relations than is the distortion energy criterion, two

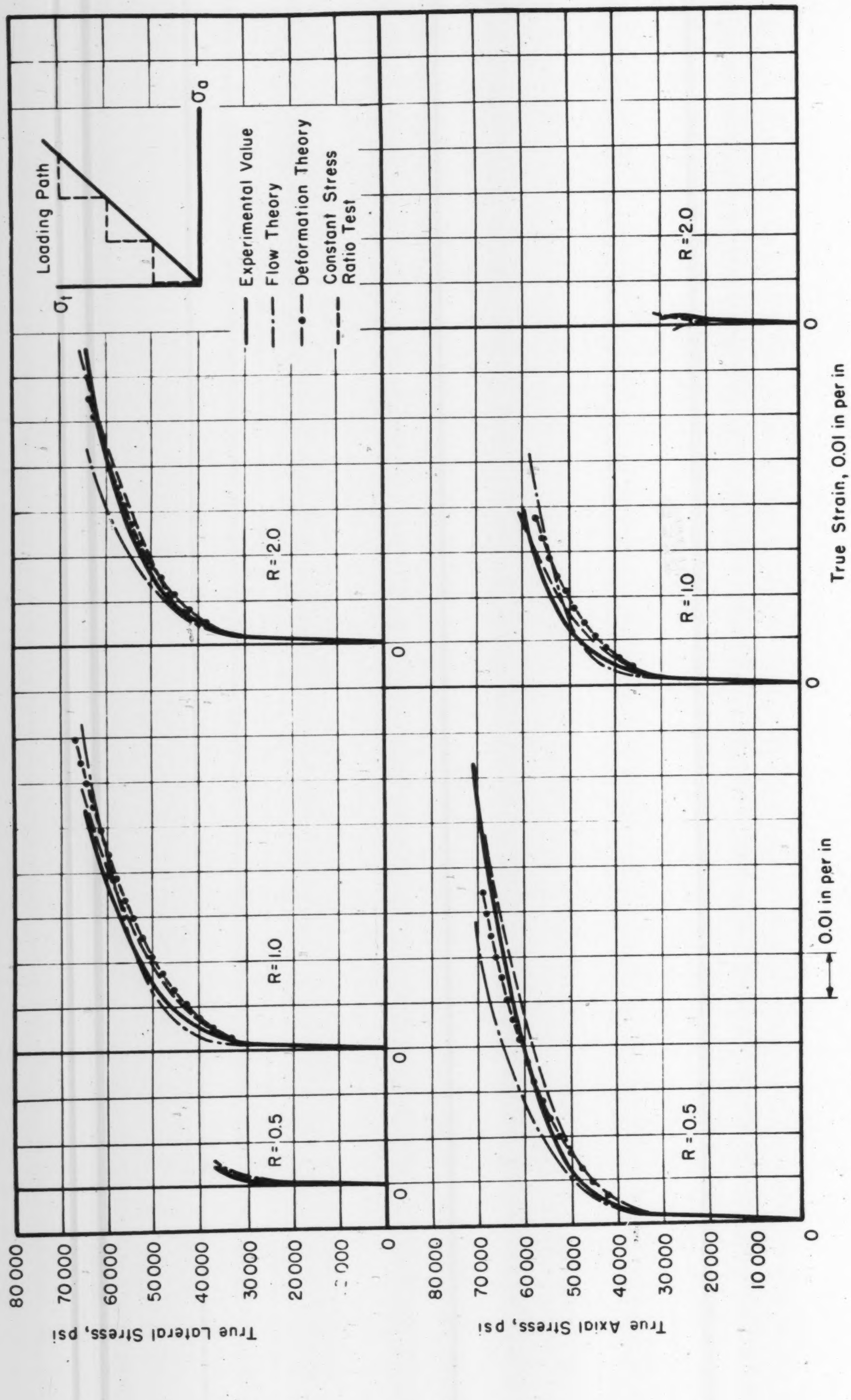

FIG. 19.—Comparison of True Stress-Strain Relations with Plasticity Theories for Special Constant Stress Ratio Tests.

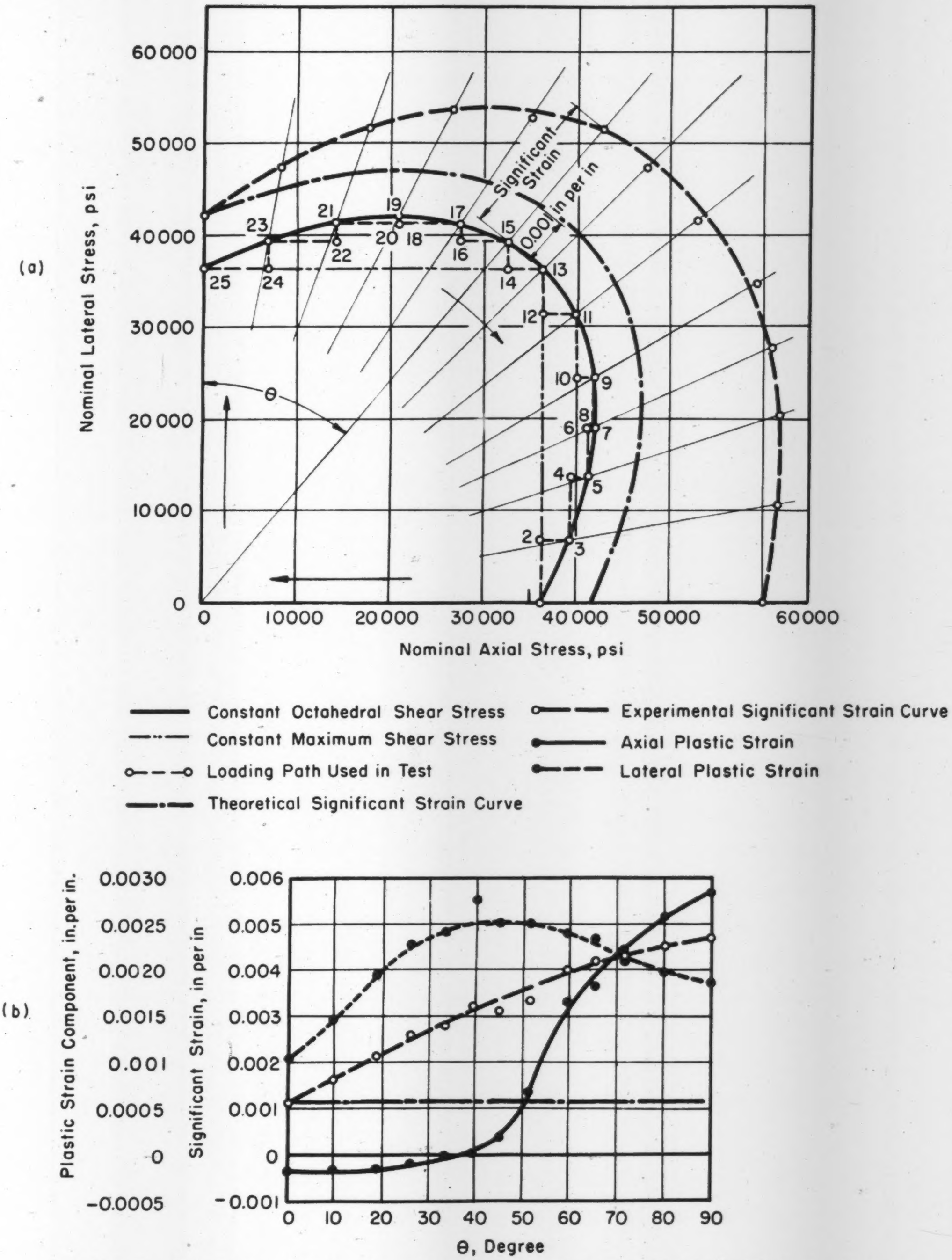

FIG. 20.—Loading Path and Comparison of Strains with Theoretical Values for Distortion Energy Loading Criterion Test—Specimen 162.

sets of tests were made. In one type of test the load was first applied in the lateral direction to a stress value (point 25 in Fig. 20) a small amount in excess of the tensile yield strength in the axial direction. The stress was then applied in the axial direction to a point 24 (Fig. 20). This loading was then followed by an increase in stress in the lateral direction to point 23 or to a stress defined by the distortion energy criterion. The stresses were then alternately applied in steps in the lateral and axial directions along the boundary represented by the distortion energy ellipse until a stress in the axial direction only remained (point 1, Fig. 20). If the distortion energy loading criterion is correct, the significant strain in going from point 25 to point 1 will not change. Another test was conducted in which the loading path followed the maximum shear loading criterion as indicated by loading path 25 to 13 and 13 to 1.

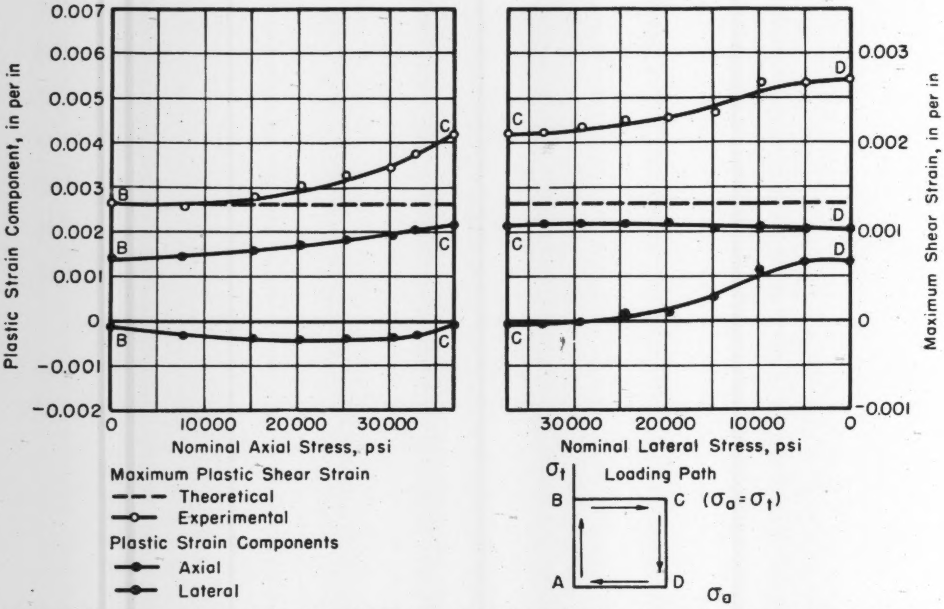

FIG. 21.—Comparison of Strains with Theoretical Values for Maximum Loading Criterion Test—Specimen 163.

Results and Analysis:

Nominal stress-strain curves were plotted for tests made to check both the distortion energy loading criterion and the maximum shear loading criterion. The variation in the strain values during the loading paths for the distortion energy and maximum shear loading criterions is shown in Figs. 20 and 21 respectively. A comparison in Figs. 20 and 21 of the values obtained by tests with theoretical values indicates that neither criterion agrees with the test results but that the maximum shear criterion is much better than the distortion energy criterion. It should be noted that, although creep may have affected the results to some extent, creep would not be sufficient to explain the discrepancies.

CONCLUSIONS

For the material tested the following conclusions can be made regarding the mechanical properties under biaxial tension:

1. Biaxial yield strengths for various stress ratios are in good agreement with the distortion energy theory.
2. True biaxial fracture strengths agree with the maximum stress theory and are independent of the path of loading.
3. Ductility, as predicted by the significant strain values, agrees approximately with test values.

Based on the foregoing tests, the following conclusions can be made regarding the agreement between tests and theories:

1. Constant stress ratio tests show good agreement between actual plastic stress-strain relations and those predicted by the flow or deformation theories.
2. Variable stress ratio test results indicate preference for the flow theory rather than the slip theories.
3. Constant stress ratio tests in which the stresses were applied alternately in increments cannot distinguish between the deformation and flow theories.

This investigation also attempted to determine the validity of certain assumptions made in the plasticity theories. The tests showed that:

1. The principal shear strains are not proportional to principal shear stresses.
2. The assumption of isotropic yielding is verified by the tests, provided the initial anisotropy of the material is considered.
3. For defining plastic flow, the maximum shear theory is in better agreement with test results than the distortion energy theory, but neither theory is satisfactory.

Acknowledgment:

The research described in this report was performed in the Plasticity Laboratory of The Pennsylvania State College under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. Dr. S. B. Batdorf and his associates at Langley Field gave many helpful suggestions in the planning of this research program. W. P. Hughes, Yoh-Han Pao, and H. A. B. Wiseman, research assistants, assisted in conducting the tests. The testing machine, special strain gage and specimens were made by S. S. Eckley, L. H. Johnson and I. Bjalme. The assistance given by the N.A.C.A. and the foregoing individuals in making possible this investigation is greatly appreciated.

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DISCUSSION

MR. C. RAPHAEL.[1]—I believe the type of curve shown is one which is true for uniaxial tests, and if we now perform a test which is biaxial, such as a pure shear test, the type of stress-strain curve which we would get is one which cannot be obtained from the uniaxial curve by a direct translation.

In other words, by varying the type of biaxial stress condition or the relationship between S_1 and S_2, we would actually get different shapes of curves. Now if this is true, it is in violation with the theories which assume that all the curves will be of the same general form or can be translated from one to the other.

Therefore, it might be a good idea if before attempting this type of testing in which the ratio between S_1 and S_2 is varied, we might find out for each type of biaxial stress condition what type of curve we do get, because it is probable that when you stop increasing S_2, and start increasing S_1, you are changing the general shape that your curve would now assume.

MR. JOSEPH MARIN (*author*).—The purpose of developing a mathematical theory of plasticity is to establish a means which may enable us to predict the behavior of a material under any complex stress-state from its known behavior under simple stress such as uniaxial tension. In this paper, it was attempted to investigate the validity of the current theories of plasticity, not only in the constant stress-ratio cases, but also in a more general situation, the variable stress ratios. As far as getting the different stress-strain relations for different stress-ratios, we did that. The results have been given in the paper.

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SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON STRENGTH AND DUCTILITY OF METALS AT ELEVATED TEMPERATURES WITH PARTICULAR REFERENCE TO EFFECTS OF NOTCHES AND METALLURGICAL CHANGES

The Joint ASTM-ASME Committee on Effect of Temperature on the Properties of Metals sponsored this Symposium at the First, Third, and Sixth Sessions of the Fifty-fifth Annual Meeting of the American Society for Testing Materials in New York, N. Y., on June 23, 1952. The papers dealt both with the effects of notches on metals at elevated temperatures and the effects on strength and ductility of metallurgical changes which occur at elevated temperatures.

The following papers were presented:

Introduction—J. D. Lubahn and G. V. Smith
A Survey of Embrittlement and Notch Sensitivity of Heat Resisting Steels—George Sachs and W. F. Brown, Jr.
Effect of a Notch and of Hardness on the Rupture Strength of "Discaloy"—F. C. Hull, E. K. Hann, and H. Scott
Influence of Sharp Notches on the Stress-Rupture Characteristics of Several Heat Resisting Alloys—W. F. Brown, Jr., M. H. Jones, and D. P. Newman
The Effect of Grain Size Upon the Fatigue Properties at 80, 1200 and 1600 F of "Precision Cast" Alloy X-40—P. R. Toolin
Investigations into the Influence of Notches on Creep Strength at High Temperatures—W. Siegfried
Theory of Time-Dependent Rupture and Interpretation of Some Stress-Rupture Data—D. N. Frey
Effect of Notch Geometry on Rupture Strength at Elevated Temperatures—E. A. Davis and M. J. Manjoine
Notch Rupture Tests of Inconel X and Nimonic 80A—D. E. Furman and A. M. Talbot
An Experimental Study of the Strength and Ductility of Steel at Elevated Temperatures—J. Glen
Effect of Sigma on Strength and Ductility of 25 Cr, 20 Ni Steel—G. V. Smith and E. J. Dulis
Recovery and Creep in an Alloy Steel—H. A. Lequear and J. D. Lubahn
The Structure and Properties of Stainless Steels After Exposure at Elevated Temperatures—A. B. Wilder and E. F. Ketterer

These papers and discussions have been issued by the ASTM as *Special Technical Publication No. 128*, entitled "Symposium on Strength and Ductility of Metals at Elevated Temperatures with Particular Reference to Effects of Notches and Metallurgical Changes."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON FRETTING CORROSION

The phenomenon of fretting corrosion was the subject of the Eighteenth and Twenty-first Sessions of the Fifty-fifth Annual Meeting of the Society, June 25, 1952, New York, N. Y. The five papers covered fretting corrosion tendencies and the effect of lubricants in minimizing this situation. The Symposium was under the sponsorship of Technical Committee G on Lubricating Grease of Committee D-2 on Petroleum Products and Lubricants.

The following papers were presented:

The Present Status of Fretting Corrosion—W. E. Campbell
Fretting Corrosion Tendencies of Several Combinations of Materials—J. R. McDowell
Fretting Corrosion in Fitted Members—O. J. Horger
Effect of Lubricants in Minimizing Fretting Corrosion—E. W. Herbek and R. F. Strohecker
Test Equipment for Evaluating Fretting Corrosion—H. H. Uhlig, W. D. Tierney, and A. McClellan

These papers and discussions are issued by the Society as *Special Technical Publication No. 144*, entitled "Symposium on Fretting Corrosion."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON TIN

The papers included in this Symposium discussed some important problems connected with tin—resources and production capabilities, fields of usage, and problems of analyses. They were presented at the Second and Fourth Sessions of the Fifty-fifth Annual Meeting of the Society held in New York, N. Y., June 23, 1952. Subcommittee III on White Metal Alloys of Committee B-2 on Non-Ferrous Metals and Alloys sponsored this symposium.

The following papers were presented:

Introductory Remarks—Bruce W. Gonser
The Production and Uses of Tin Coatings—F. Stuart Miller
Tin Coatings—Frederick A. Lowenheim
Trends in the Use of Tin in the Container Industry—Robert R. Hartwell
Tin in Automobile Body Construction—Homer Pratt
The Effect of Impurities on the Performance of Tin—C. L. Mantell
The Determination of Small Amounts of Impurities in Tin—Marie Farnsworth and Joseph Pekola

These papers together with discussions were issued as *ASTM Special Technical Publication No. 144*, entitled "Symposium on Tin."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON DETERMINATION OF ELASTIC CONSTANTS

This Symposium was presented at the Seventeenth Session of the Fifty-fifth Annual Meeting of the Society held in New York, N. Y., June 25, 1952, and was sponsored by the Task Group on Elastic Constants of Committee E-1 on Methods of Testing. The papers dealt with the various methods, with their advantages and disadvantages, employed in determining elastic constants of different materials.

The following papers were presented:

Introduction—Walter Ramberg
Report on ASTM Task Group for Determination of Elastic Constants—Walter Ramberg
The Influence of Temperature on the Elastic Constants of Some Commercial Steels—F. Garofalo, P. R. Malenock, and G. V. Smith
Methods for Determining the Elastic Constants of Non-Metallic Materials—E. W. Kuenzi
Dynamic Methods for Determining the Elastic Constants and Their Temperature Variation in Metals—M. E. Fine
An Evaluation of Several Static and Dynamic Methods for Determining Elastic Moduli—John T. Richards

These papers and their discussions have been issued as *ASTM Special Technical Publication No. 129,* entitled "Symposium on Determination of Elastic Constants."

CHEMICAL TEST FOR ALKALI REACTIVITY OF POZZOLANS*

By Richard C. Mielenz,[1] Kenneth T. Greene,[1] Elton J. Benton,[1] and Fred H. Geier[1]

Synopsis

A new chemical test will indicate quickly the ability of a pozzolan to control expansion of mortar resulting from reaction between cement alkalies and susceptible aggregates. The test can be performed and necessary analyses can be completed in two work-days. The reduction in alkali concentration of a 0.5 *N* sodium hydroxide solution after reaction with the pozzolan in the presence of calcium hydroxide is taken as an index of the alkali reactivity of the pozzolan. A correlation is demonstrated between the results of the new test and the Pyrex mortar-bar expansion test for 63 pozzolans.

A reduction in alkali concentration (reactivity index) of 180 or greater, expressed as milliequivalents per liter, is taken as the criterion of a satisfactory pozzolan from the standpoint of control of alkali-aggregate expansion.

The test is recommended for use in specifications covering selection and control of pozzolans.

The use of pozzolanic materials in mortar and concrete dates from ancient times. Pozzolans have been employed to improve the properties of the finished product to effect economies. The fundamental pozzolanic reaction takes place between siliceous (and occasionally aluminous) constituents of the pozzolan and calcium hydroxide liberated by hydration of the cement, with resulting formation of products which augment the strength developed by the cement (**1**).[2] However, in recent years a secondary and largely independent reaction has been recognized, involving the alkali hydroxides produced by dissolution or hydration of the cement constituents which contain sodium and potassium.

Soon after his original description of the alkali-aggregate reaction in concrete, published in 1940 (**2**), T. E. Stanton reported his investigations in greater detail and summarized data demonstrating the effectiveness of certain siliceous admixtures in preventing or reducing the expansion caused by alkali-aggregate reaction (**3**). Subsequent work conducted by various laboratories has proved that many pozzolans will effectively counteract this reaction (**1, 4**).

Most generally used of the tests for evaluating the ability of a pozzolan to control expansion caused by alkali-aggregate reaction is the mortar-bar expansion test in which a standard reactive aggregate, such as Pyrex, is combined with a high-alkali cement and the pozzolan (**1**, pp. 123–125). In this test a stipulated percentage of the cement is replaced by pozzolan and the average expansion of three bars at selected ages during moist storage is compared with the expansion of similarly prepared and cured control specimens containing the same cement and aggregate but no pozzolan. A reduction in expansion of 75 per cent or greater at 14 days' age when the pozzolan replaces 20 per cent by weight or 25 per cent by volume of the high-alkali cement is considered to be necessary in order that a pozzolan be satisfactory for controlling alkali-aggregate reaction. The chief disadvantages of the mortar-bar test are the time required to obtain definitive results (two weeks to two months) and the typically poor reproducibility. The need for rapid testing is acute because pozzolans usually are delivered direct to the job from the plant without interim storage.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Head, Petrographic Laboratory; Chemist (petrography); Chemist; and Chemist, respectively, Bureau of Reclamation, Denver, Colo.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1144.

This paper describes a quick chemical test for alkali reactivity of pozzolans, which has been developed to fulfill a part of this need. The results of the test are evaluated by correlation with data derived from the mortar test. However, this should not be taken to imply that the mortar test is considered to be completely reliable. Rather, the comparison is made because the mortar test has supplied the only compact body of data on the alkali reactivity of a wide variety of types of pozzolans. Because of the very limited use of pozzolans in past construction, service records bearing upon alkali reactivity of pozzolans are available now for very few materials. However, with passing time significant records of service will become available for use in evaluating proposed new test procedures.

The chemical test is performed on the pozzolan alone; consequently, the influence of extraneous variations in properties of the reference cement is eliminated. However, important physical properties such as particle size distribution and porosity within particles, which would affect the behavior of the material in mortar or concrete, are but vaguely indicated by a test of this kind.

The investigations incidental to development of the test have supplied significant information upon the physical-chemical processes by which pozzolans effect control of the alkali-aggregate reaction, upon the influence of certain additions, and upon the relative influence of potassa as against soda in the reaction with pozzolans. Presentation of most of these data will be reserved for the future.

TEST PROCEDURE

Development:

Previous work has demonstrated that the alkali-aggregate reaction involves chemical attack upon certain siliceous rocks and minerals by sodium and potassium released during the hydration of portland cement. As a consequence of the reaction, alkalic silica gels are produced within or upon susceptible particles of aggregate (**5**). With progressive absorption of water by the gels, osmotic or swelling pressures accumulate and, if sufficient, will cause distension and cracking of the enclosing mortar. The observation that certain siliceous minerals and rocks inhibit or prevent the alkali-aggregate reaction when they are finely ground and admixed as a pozzolan in mortar or concrete, immediately suggests that the alkalies preferentially attack the pozzolan and are permanently bound in the resulting reaction products.

An approach to the reaction system involving high-alkali portland cement and a pozzolan can be achieved by mixing an amount of a pozzolan and a quantity of calcium hydroxide with an aqueous solution of sodium hydroxide, potassium hydroxide, or a mixture of the two. Although the sulfate ion released from gypsum during hydration of the cement might slightly influence the course of the alkali-aggregate reaction, its presence in ordinary amounts is not necessary to

TABLE I.—CHEMICAL TEST RESULTS AND MORTAR-BAR EXPANSION DATA ON POZZOLANS.

Sample	Laboratory Designation	Pozzolan	Source	Heat Treatment	Reduction in Sodium, me per liter	Potassium Released, me per liter	Net Reduction in Alkali ($Na^+ + K^+$), me per liter	Reduction in Alkalinity (OH^-), me per liter	Concentrations,		Reduction in Expansion of Mortar,[a] per cent of control		
									Silica mM per liter	Aluminum me per liter	14 da	2 mo	1 yr
No. 1......	7259	Pulverized slag	Rockmart, Ga	None	128	28	100	120	4.4	...	58	72	72
No. 2......	7310	Pumicite	Near Ellis, Kans	None	152	36	116	188	7.2	...	74	80	72
No. 3......	8640	Pumicite	Near Ellis, Kans	None	180	39	141	174	12.4	...	67	78	78
No. 4......	7926	Opaline shale	Near Colton, Calif	None	176	4	172	226	2.0	4.1	80	77	52
No. 5......	7926	Opaline shale	Near Colton, Calif	800 F	177	4	173	223	2.8	4.4	75	80	65
No. 6......	A 7926	Opaline shale	Near Colton, Calif	1000 F	204	1	203	252	2.4	4.1	81	86	75
No. 7......	7926	Opaline shale	Near Colton, Calif	1200 F	208	4	204	264	2.4	6.9	87	89	78
No. 8......	7926	Opaline shale	Near Colton, Calif	1400 F	232	1	231	280	3.2	6.8	82	86	80
No. 9......	7926	Opaline shale	Near Colton, Calif	1600 F	263	4	259	310	2.8	4.9	84	88	80
No. 10......	8147	Opaline shale	Near Colton, Calif	Plant calcined	192	5	187	231	2.4	6.2	78	84	79
No. 11......	A-268	Opaline shale	Near Colton, Calif	Plant calcined	272	4	268	285	4.0	3.2	84	81[b]	...
No. 12......	A-548	Opaline shale	Near Colton, Calif	Plant calcined	232	4	228	245	4.0	8.5	74		
No. 13......	8348	Argillaceous sandy silt	Near Louisville, Nebr	None	28	3	25	24	0.4	7.2	31	29	17
No. 14......	8348	Argillaceous sandy silt	Near Louisville, Nebr	800 F	28	11	17	16	1.6	8.0	22	28	27
No. 15......	8348	Argillaceous sandy silt	Near Louisville, Nebr	1000 F	24	11	13	21	0.4	8.1	22	22	23
No. 16......	8348	Argillaceous sandy silt	Near Louisville, Nebr	1200 F	24	11	13	21	0.4	8.6	28	29	20
No. 17......	8348	Argillaceous sandy silt	Near Louisville, Nebr	1400 F	16	11	5	22	0.8	11.2	28	35	30
No. 18......	8348	Argillaceous sandy silt	Near Louisville, Nebr	1600 F	32	17	15	18	0.4	14.9	41	44	37
No. 19......	8348	Argillaceous sandy silt	Near Louisville, Nebr	1800 F	32	27	5	22	0.4	16.1	44	51	47
No. 20......	8318	Argillaceous sandy silt	Near Louisville, Nebr	Plant calcined	28	16	12	18	0.4	12.0	18	32	24
No. 21......	A-799	Argillaceous sandy silt	Near Louisville, Nebr	Plant calcined	68	12	56	63	1.6	16.6	56	52[c]	51
No. 22......	8383-1	Opaline rhyolite tuff	Near Kalispell, Mont	1400 F	341	0	341	370	4.4	...	91	96	95
No. 23......	8383-2	Opaline rhyolite tuff	Near Kalispell, Mont	None	332	0	332	370	52.4	...	96	95	86
No. 24......	8383-2	Opaline rhyolite tuff	Near Kalispell, Mont	1400 F	382	0	382	420	17.2	...	92	96	95
No. 25......	8383-3	Altered rhyolite tuff	Near Kalispell, Mont	1400 F	152	8	144	165	2.0	8.5	83	91	90
No. 26......	A-775	Opaline rhyolite tuff	Near Kalispell, Mont	None	324	0	324	370	28.0	...	98	98[c]	97
No. 27......	A-775	Opaline rhyolite tuff	Near Kalispell, Mont	1400 F	382	0	382	417	6.4	...	92	93[c]	90
No. 28......	8501	Opaline shale	Near Santa Cruz, Calif	None	344	1	343	373	121.	...	96	96	94
No. 29......	8501	Opaline shale	Near Santa Cruz, Calif	800 F	344	1	343	375	114.	...	97	96	93
No. 30......	8501	Opaline shale	Near Santa Cruz, Calif	1000 F	356	1	355	380	106.	...	96	96	93
No. 31......	8501	Opaline shale	Near Santa Cruz, Calif	1200 F	356	1	355	378	116.	...	98	97	95
No. 32......	8501	Opaline shale	Near Santa Cruz, Calif	1600 F	352	1	351	377	117.	...	97	97	95
No. 33......	8501	Opaline shale	Near Santa Cruz, Calif	1800 F	336	3	333	353	142.	...	93	95	94
No. 34......	8920	Pumicite	Near Calvert, Kans	None	216	24	192	229	10.0	...	82	82	77
No. 35......	9126-1	Pumicite	Near Arlington, Oreg	None	252	30	222	246	13.4	...	86	83	71
No. 36......	9126-1	Pumicite	Near Arlington, Oreg	800 F	256	30	226	245	13.4	...	81	79	69
No. 37......	9126-1	Pumicite	Near Arlington, Oreg	1000 F	248	30	218	245	13.4	...	69	69	56
No. 38......	9126-1	Pumicite	Near Arlington, Oreg	1200 F	252	30	222	287	13.6	...	80		
No. 39......	9126-1	Pumicite	Near Arlington, Oreg	1400 F	240	35	205	225	12.6	...	85	82	70

No. 40.......	9126-1	Pumicite	Near Arlington, Oreg	1600 F	208	36	172	195	11.8	...	84	82	71
No. 41.......	9126-1	Pumicite	Near Arlington, Oreg	1800 F	68	36	32	45	1.2	...	56	58	51
No. 42.......	9397	Siliceous shale	Near Laramie, Wyo	1400 F	108	4	104	123	2.0	12.2	63	57	49
No. 43.......	9407	Fly ash	Chicago, Ill	None	16	25	−9	85	2.0	12.4	63	67	65
No. 44.......	9980, 1, 2	Fly ash	Milwaukee, Wis	None	80	26	54	83	2.0	25.0	41	58	57
No. 45.......	9446	Altered pumicite	Near Whitehall, Mont	None	136	4	132	199	2.0	21.7	60	34	7
No. 46.......	9446	Altered pumicite	Near Whitehall, Mont	1400 F	203	8	195	237	4.4	...	83	83	77
No. 47.......	A-168-2	Altered pumicite	Near Whitehall, Mont	None	174	6	168	228	3.2	25.9	40	18	5
No. 48.......	A-94	Pumicite	Near Wallace, Calif	None	252	30	222	270	12.0	12.4	79		
No. 49.......	A-94	Pumicite	Near Wallace, Calif	1400 F	272	32	240	257	14.2	...	89	86	79
No. 50.......	A-107	Altered pumicite	Near Rio Grande City, Tex	None	152	6	146	157	2.0	7.5	61		
No. 51.......	A-107	Altered pumicite	Near Rio Grande City, Tex	1400 F	270	14	256	274	5.2	...	85	80	77
No. 52.......	9444	Kaolin	Bath, South Carolina	1400 F	212	0	212	205	2.0	250.	99	98	94
No. 53.......	9445	Clay	Near Ivie, Utah	1400 F	396	0	396	425	16.0	2.3	85	90	81
No. 54.......	A-245	Oil-impregnated shale	Near Casmalia, Calif	Plant calcined	182	16	166	226	3.2	3.8	73	67	59
No. 55.......	A-974	Oil-impregnated shale	Near Casmalia, Calif	Plant calcined	332	4	328	403	13.8	...	81	72[c]	70
No. 56.......	A-95	Kaolin	Near Valley Springs, Calif	None	46	4	42	48	2.0	5.4	53	25	7
No. 57.......	A-101	Spent oil shale	Near Rifle, Colo	Plant retorted	−8	10	−18	18	2.4	2.8	52	30	30
No. 58.......	A-226	Pumicite	Near Altaville, Calif	None	188	44	144	166	6.4	...	72		
No. 59.......	A-688	Pumicite	Near Whittier, Calif	None	56	32	24	59	1.6	30.5	56	60[c]	57
No. 60.......	A-765	Silt	Near McCook, Nebr	1400 F	40	10	30	50	2.0	8.8	43	43[c]	40
No. 61.......	8322	Quartz	Buffalo Park, Colo	None	44	1	43	28	2.0	0.4	6	15	14
No. 62.......	P-2026	Opal	Near Quincy, Wash	None	388	0	388	395	117.	0.1	86	96	90
No. 63.......	8345	Pyrex glass	Corning Glass Works, Corning, N Y	None	198	1	197	212	53.8	...	92	87	79

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[a] Reduction in expansion of 1- by 1- by 11¼-in. mortar bars, compared to expansion of control specimen. For control specimens, mix proportions are 1 part high-alkali portland cement and 2.25 parts by weight graded crushed Pyrex as aggregate; for test specimens, 20 per cent by weight or 25 per cent by volume of the cement is replaced by pozzolan. Specimens are cured in moist room at 70 F and 95 per cent relative humidity for 24 hr, then stored at 100 F in sealed cans over but not in contact with excess water. Reduction in expansion is calculated as percentage of the expansion of the control specimen.

[b] Age: twenty-eight days.

[c] Age: three months.

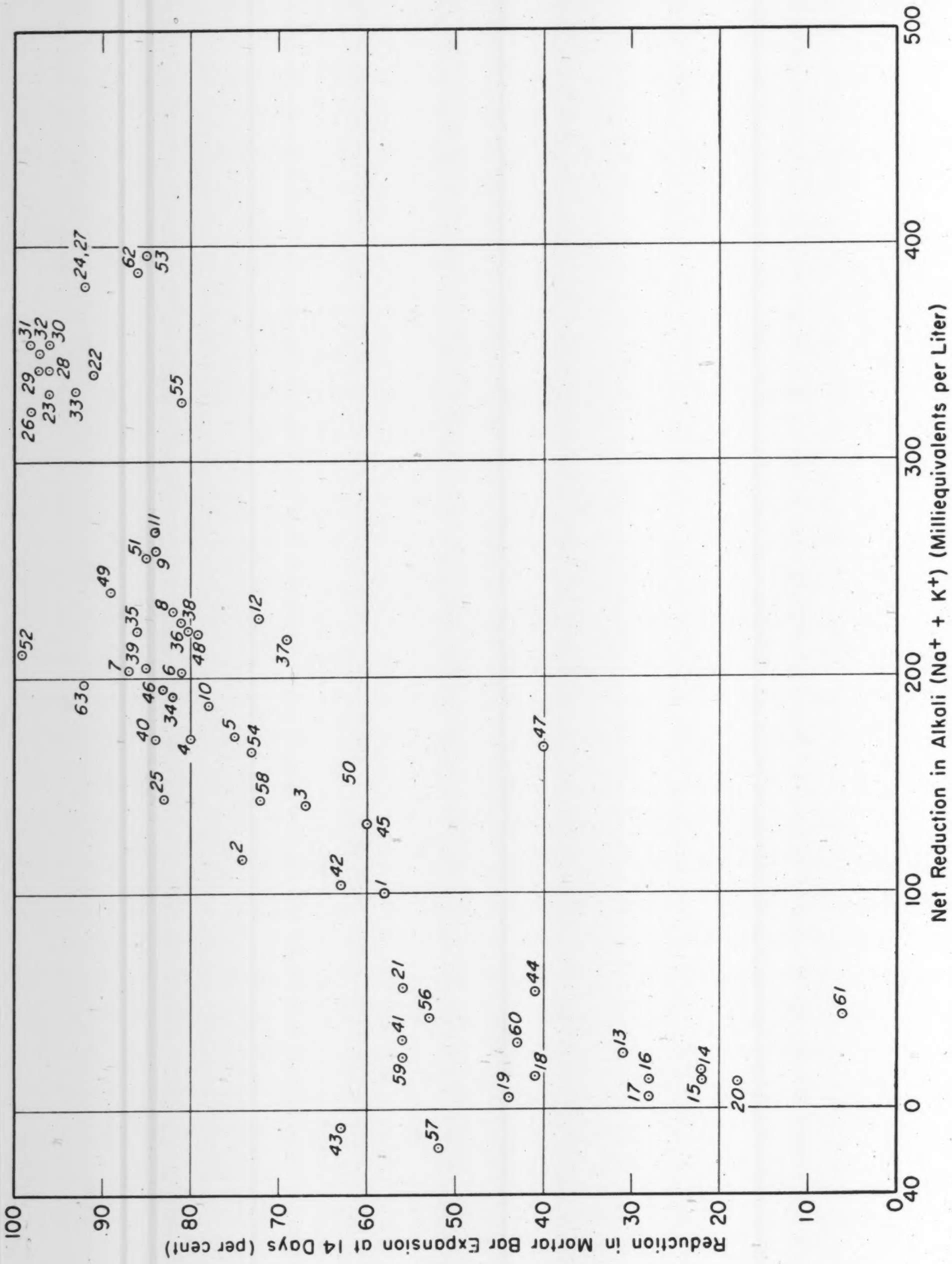

FIG. 1.—Correlation of Reduction of Concentration of Alkalies (Reactivity Index) in the Chemical Test with Reduction in Expansion of Mortar Bars at 14 Days.

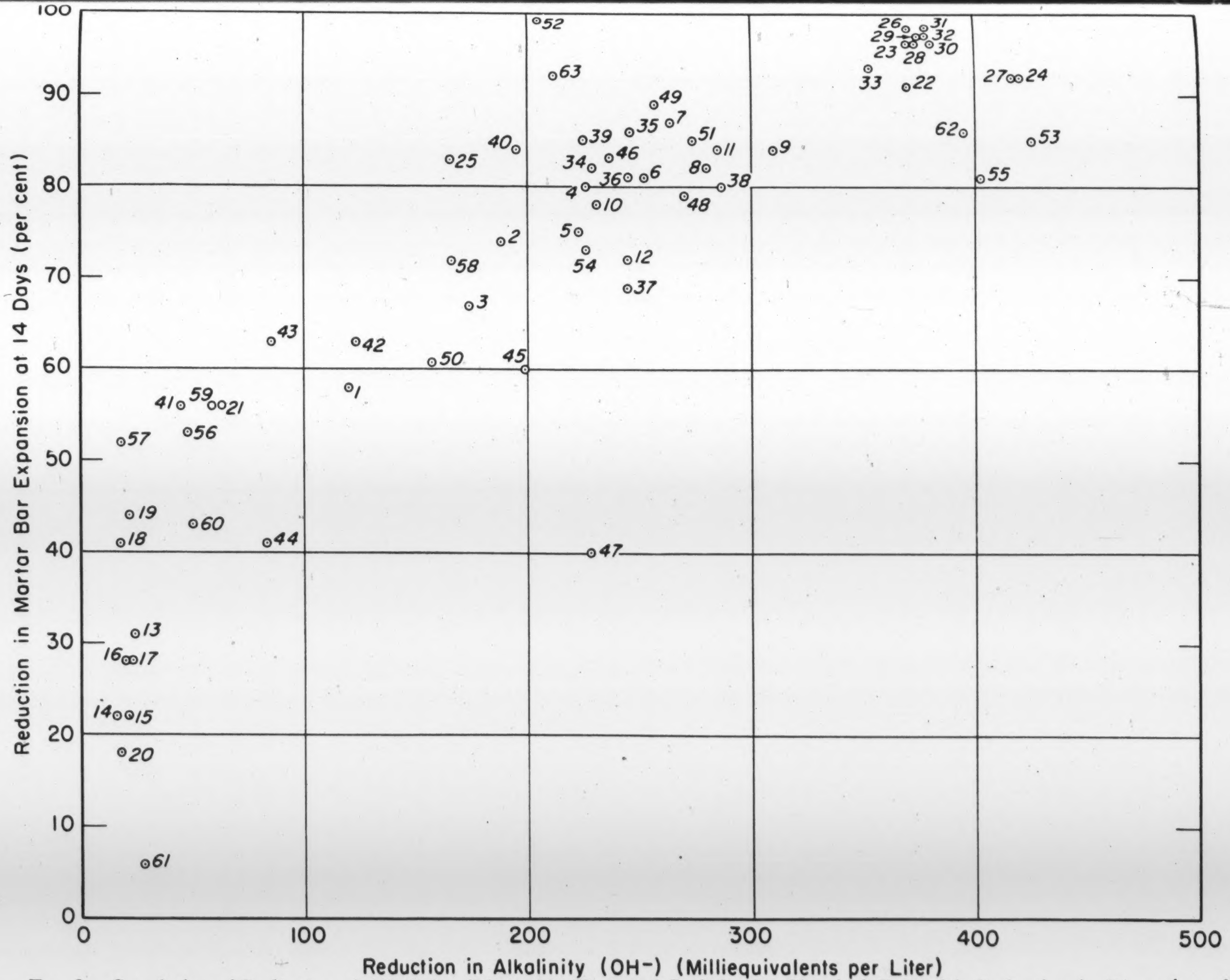

FIG. 2.—Correlation of Reduction of Alkalinity (Titratable Hydroxyl Ion) in the Chemical Test with Reduction in Expansion of Mortar Bars at 14 Days.

development of the resulting expansion (5). Consequently, the sulfate ion might well be omitted from the mixture.[3]

A realistic ratio of the amount of pozzolan to the amount of calcium hydroxide to be used in the test can be derived by assuming a proportionality between pozzolan and portland cement in a blend and then calculating from average analyses of portland cements the amount of calcium hydroxide released by hydration of the tricalcium silicate. The quantity of alkali could be selected either as a proportion by weight of the assumed amount of cement or as a concentration. Selection of a concentration is the more appropriate since the weight of alkali hydroxide equivalent to that released by the cement would yield a very low concentration in the solution, if sufficient solution is used to assure an excess for analysis at completion of the test. Based upon preliminary tests, the following factors were established:

Assumed ratio of pozzolan to cement (by weight)	1 to 3
Assumed C_3S content of the cement	40 per cent
Selected concentratron of alkali	0.5 *N* NaOH
Amount of solution	25 ml
Weight of pozzolan used	4.0 g
Weight of $Ca(OH)_2$ used	1.5 g

Method:

In the procedure, 4.00 g of pozzolan is caused to react with 25 ml of 0.5 *N* sodium hydroxide solution and 1.50 g of solid finely ground calcium hydroxide at 80 C during continuous agitation for a period of 24 hr.[4] At the end of the reaction period the residual solids and newly formed reaction products are filtered off. The reduction in concentration of sodium in the filtrate is determined. Analysis for potassium is also made, and any potassium released into the solution by the pozzolan is considered to negate some of the reduction which otherwise would be indicated. Reduction in alkalinity may be determined by titration of the filtrate if desired.

Results of the Tests with Sodium Hydroxide

Summary of Data:

Results of the chemical test applied to 63 pozzolans representing a variety of materials are given in Table I. Reduction in sodium concentration, potassium released, and net reduction in alkali concentration are shown, as well as the reduction in alkalinity obtained by titration. Net reduction in alkali ranges from −18 milliequivalents per liter,[5] for a spent oil shale (sample No. 57), to 396 milliequivalents per liter for a clay calcined at 1400 F (sample No. 53). Reduction in alkalinity ranges from 16 milliequivalents per liter for an argillaceous sandy silt calcined at 800 F (sample No. 14) to 425 milliequivalents per liter for the clay calcined at 1400 F (sample No. 53). Potassium released ranges from zero for eight materials to 44 milliequivalents per liter for a pumicite (sample No. 58).

Correlation with Expansion of Mortars:

Reduction in expansion of mortar bars containing reactive Pyrex aggregate, high-alkali cement, and the tested pozzolans for ages of 14 days, 2 months, and 1 year is given in Table I. In Figs. 1 and 2 are plotted the net reduction in alkali (Na^+ and K^+) and the reduction in alkalinity (OH), respectively, against the reduction in expansion of mortar bars at

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[3] Experiments were performed in which the described chemical test procedure was followed except that gypsum was added in an amount corresponding to that which would be derived from an average cement if the cement were present to the extent of three times the pozzolan by weight. The general effect was to lower the reduction in alkali concentration compared to tests made without added gypsum, indicating that the reaction is less complete, possibly through suppression of the solubility of calcium hydroxide. The correlation with the mortar-bar test was less satisfactory than when gypsum was omitted.

[4] See Appendix II for a detailed description of the procedure.

[5] Negative values of reduction indicate net increase in concentration of alkalies through release of alkalies by the pozzolan.

14 days' age for the materials listed in Table I.

The distribution of points and degree of correlation are similar for the two graphs, all except two pozzolans causing net reduction in alkali concentration (reactivity index) of 180 or greater cause reduction in mortar-bar expansion at 14 days of 75 per cent or more (Fig. 1). On the other hand, four materials having a reactivity index somewhat below 180 also cause reduction in expansion of 75 per cent or more. On the basis of these data, 180 or greater appears to be a reasonable criterion of satisfactory alkali reactivity.

Considering the data of Fig. 2 in a similar way, all except four pozzolans showing reduction in alkalinity of 210 or greater cause reduction in mortar-bar expansion of 75 per cent or more, whereas only three materials giving reduction in alkalinity of less than 210 cause reduction in expansion of more than 75 per cent. This indicates that for the types of materials represented, a criterion of 210 milliequivalents per liter in reduction in alkalinity is approximately equivalent to 180 milliequivalents per liter in net reduction in alkali. For such materials, the simpler procedure of titrating with standard acid for determination of reduction in alkalinity could be substituted for the more involved method of analyzing for sodium and potassium with the flame photometer. However, the titration method cannot be used with materials containing significant amounts of carbonates of magnesium or iron, such as dolomite or siderite. These constituents react with sodium hydroxide to produce insoluble hydroxides, resulting in a reduction in alkalinity unrelated to the mechanism by which pozzolans control alkali-aggregate reaction.

TABLE II.—CHEMICAL TEST RESULTS ON POZZOLANS SUPPLIED BY THE PORTLAND CEMENT ASSOCIATION.

PCA Sample	Pozzolan	Reduction in Sodium, me per liter	Potassium Released, me per liter	Net Reduction in Alkali ($Na^+ + K^+$), me per liter	Reduction in Alkalinity (OH^-), me per liter
No. 16286	Fresno pumicite	28	36	−8	18
No. 16313	Calcined Monterey shale	296	4	292	373
No. 17990	Fused clay-lime mixture	168	26	142	185
No. 17991	Calcined clay from Kansas	116	10	106	142
No. 17993	Fresno pumicite[a]	164	48	116	157
No. 18090	Calcined clay from Nebraska	32	2	30	23
No. 18092	Fly-ash clinker	88	2	86	88

[a] Fresno pumicite, No. 17993, is ground much finer than sample No. 16286.

Correlation between the results of the chemical test and the mortar-bar expansion test is somewhat less satisfactory if mortar-bar data at ages of 2 months and 1 year, in contrast to 14 days, are considered. This fact, as well as the anomalous results obtained with a few materials at all three ages, is believed to reflect the influence of physical factors, such as particle size distribution and porosity, which are largely undetected by the chemical test. Moreover, slight differences in distribution of fractures and in physical structure of the mortar, variations in the cement used, and changing conditions within the storage containers may produce significant variations in results of the expansion test.

Additional data bearing on the correlation of the chemical test with behavior of pozzolans in mortar and concrete are provided by results of the test performed on seven samples supplied by Mr. William Lerch of the Portland Cement Association (Table II). Data published by Mr. Lerch indicate that of these materials, the calcined Monterey shale (No. 16313) is most effective in controlling alkali-aggregate reaction (1). This agrees with the chemical test results, since the calcined Monterey shale is the only material which caused a net reduction in concentration of alkalies greater than 180 and a reduction in alkalinity greater than 210, the criteria of satisfactory alkali reactivity previously mentioned. Tests with concrete beams stored outdoors for six years are reported by Mr. Lerch for two of these materials (1). The calcined Monterey shale (No. 16313) prevented development of pattern cracking; whereas Fresno pumicite (No. 16286) failed to prevent it under these conditions of exposure.

TABLE III.—REPRODUCIBILITY OF RESULTS IN CHEMICAL TEST.

Sample	Pozzolan	Heat Treatment	Number of Determinations	Average Reactivity Index	Range	Standard Deviation
No. 9	Opaline shale	1600 F	8	260.3	22	9.61
No. 17	Argillaceous sandy silt	1400 F	8	18.1	45	14.5
No. 43	Fly ash	None	8	−19.6	24	9.05
No. 52	Kaolin	1400 F	7	240.4	34	11.3
No. 62	Opal	None	7	383.7	22	7.37

TABLE IV.—REPRODUCIBILITY OF RESULTS IN MORTAR-BAR EXPANSION TEST.

Sample	Pozzolan	Heat Treatment	Test	Reduction in Expansion of Mortar[a]		
				14 days	2 months	1 yr
No. 2	Pumicite	None	No. 1 No. 2	74 86	80 87	72 84
No. 4	Opaline shale	None	No. 1 No. 2	80 76	77 57	52 46
No. 20	Argillaceous sandy silt	Plant calcined	No. 1 No. 2 No. 3	18 30 11	32 27 30	24 24 21
No. 62	Opal	None	No. 1 No. 2 No. 3	86 94 86	96 96 91	90 93 90
	Rhyolite tuff (No. P-227)[b]	None	No. 1 No. 2 No. 3	31 29 20	20 21 21	8 13 20
	Opaline shale (No, P-129)[b]	Plant calcined	No. 1 No. 2 No. 3 No. 4	88 86 82 87	91 89 84 95	85 85 78 89
	Altered rhyolite tuff (No. P-180)[b]	1400 F	No. 1 No. 2 No. 3 No. 4	78 74 80 85	71 64 76 82	65 55 73 80
	Travertine (No. 3409)[b]	None	No. 1 No. 2	55 31	44 32	33 25

[a] See footnote *a*, Table I.
[b] Not subjected to chemical test.

Reproducibility:

Five of the pozzolans included in the investigations were selected for repeated testing to determine the reproducibility of the chemical test. Seven determinations were made on each of two materials and eight on each of the other three. The seven determinations represent two tests in duplicate and one test in triplicate, at three different times. The eight determinations represent one test in duplicate and two tests in triplicate, at three different times. Average values of the reactivity index (net reduction in concentration of Na^+ and K^+) and ranges and standard deviations were calculated for each material (Table III). The ranges and standard deviations are of the same order of magnitude for the five materials. Agreement between duplicate or triplicate determinations made at the same time is considerably better than the over-all reproducibility.

Corresponding reproducibility data on the mortar-bar test are sparse. However, four of the pozzolans subjected to the chemical test have been tested either two or three times, and four pozzolans not subjected to the chemical test have been tested either two, three, or four times (Table IV). These data indicate the degree of reproducibility commonly obtained in the mortar-bar test.

TABLE V.—CHEMICAL TEST RESULTS WITH POTASSIUM HYDROXIDE.[a]

Sample	Pozzolan	Heat Treatment	Reduction in Potassium, me per liter	Sodium Released, me per liter	Net Reduction in Alkali ($Na^+ + K^+$), me per liter	Reduction in Alkalinity (OH^-), me per liter
No. 9.........	Opaline shale	1600 F	262	0	262	279
No. 17.........	Argillaceous sandy silt	1400 F	20	0	20	11
No. 22.........	Opaline rhyolite tuff	1400 F	276	0	276	268
No. 39.........	Pumicite	1400 F	146	24	122	134
No. 43.........	Fly ash	None	12	42	−30	70
No. 62.........	Opal	None	384	0	384	377

[a] Tests performed in accordance with procedure described in Appendix II, except that 0.5 *N* potassium hydroxide was substituted for sodium hydroxide.

TABLE VI.—CHEMICAL TEST RESULTS WITH MIXED SODIUM AND POTASSIUM HYDROXIDES.[a]

Sample	Pozzolan	Heat Treatment	Reduction in Sodium, me per liter	Reduction in Potassium, me per liter	Net Reduction in Alkali ($Na^+ + K^+$), me per liter	Reduction in Alkalinity (OH^-), me per liter
No. 9.........	Opaline shale	1600 F	116	127	243	278
No. 17.........	Argillaceous sandy silt	1400 F	11	2	13	20
No. 43.........	Fly ash	None	−10	−10	−20	81
No. 52.........	Kaolin	1400 F	93	106	199	200
No. 62.........	Opal	None	172	226	398	415

[a] Tests performed in accordance with procedure described in Appendix II, except that a 1:1 mixture by volume of 0.5 *N* sodium hydroxide and 0.5 *N* potassium hydroxide was substituted for sodium hydroxide.

SUPPLEMENTARY RESULTS WITH POTASSIUM HYDROXIDE

Tests were performed on a number of pozzolans following the described procedure of the test except that 0.5 *N* potassium hydroxide was substituted for the sodium hydroxide solution (Table V). For most pozzolans the net reduction in alkali concentration and reduction in alkalinity are similar to those obtained with sodium hydroxide, although somewhat lower. The net reduction in alkali ranges from −30 milliequivalents per liter (an increase in alkali concentration due to release of sodium by the pozzolan) for a fly ash (sample No. 43) to 384 milliequivalents per liter for opal (sample No. 62). Reduction in alkalinity ranges from 11 milliequivalents per liter for an argillaceous sandy silt calcined at 1400 F (sample No. 17) to 377 milliequivalents per liter for opal (sample No. 62).

Some of the same pozzolans also were tested with a 1:1 mixture by volume of 0.5 *N* sodium hydroxide and 0.5 *N* potassium hydroxide (Table VI). Results of these tests also are comparable to those obtained with the sodium hydroxide solution. The reduction in sodium concentration ranges from −10 milliequivalents per liter for the fly ash (sample No. 43) to 172 milliequivalents per liter for opal (sample No. 62). The reduction in potassium concentration ranges from −10 milliequivalents per liter for the fly ash (sample No. 43) to 226 milliequivalents per liter for opal (sample No. 62). Net reduction in alkali concentration (reduction in concentration of Na^+ and K^+) ranges from −20 milliequivalents per liter for the fly ash (sample No. 43) to 398 milliequivalents per liter for opal (sample No. 62). Reduction in alkalinity ranges from 20 milliequivalents per liter for the argillaceous sandy silt (sample No. 17) to 415 milliequivalents per liter for opal (sample No. 62). For the more reactive pozzolans, the reduction in potassium concentration generally is greater than is the reduction in sodium concentration, indicating that the test using sodium hydroxide alone will be on the conservative side in predicting the ability of a pozzolan to control alkali-aggregate reaction when used with cements containing both sodium and potassium. However, additional tests might demonstrate that somewhat different criteria of satisfactory reactivity would be appropriate where pozzolans are used in concrete or mortar with cements predominantly high in potassium.

TABLE VII.—RELATION OF PRECIPITATION OF SILICA BY CALCIUM HYDROXIDE TO REDUCTION IN SODIUM CONCENTRATION.[a]

Weight of Silica Added,[b] g	Potential Silica Concentration,[c] mM per liter	Actual Silica Concentration at End of Test, mM per liter	Reduction in Sodium, me per liter
0.040	27	1.0	24
0.080	53	1.2	24
0.012	80	1.0	28
0.016	107	0.6	32
0.225	150	1.2	20
0.280	187	1.2	40
0.300	200	2.8	20
0.450	300	2.6	28
0.600	400	2.2	46
0.750	500	2.2	60

[a] Tests performed in accordance with procedure described in Appendix II, using indicated amounts of silica but no pozzolan.

[b] Amorphous silica (SiO_2) prepared by precipitation from ethyl silicate with ammonium hydroxide, followed by heating to drive off volatile products.

[c] Concentrations of silica which would exist if silica added were all in solution at one time. It is recognized that actually the silica progressively dissolves and is precipitated by reaction with the calcium hydroxide.

INTERPRETATION OF THE TEST

Reduction in Concentration of Alkalies:

The mechanism by which a pozzolan counteracts the deleterious action of alkalies on susceptible aggregates is not fully understood. Nevertheless, the available evidence indicates that the pozzolan probably removes sodium and potassium ions from the solution in the hydrating cement paste through their incorporation in complex alkali-calcium-silica gels. These gels are produced partly by the ordinary cement hydration and partly by reaction between the pozzolan and the calcium and alkali hydroxides released by the cement. The gels contain relatively low concentrations of alkalies and high concentrations of calcium, with the result that they have little capacity for expansion. This lack of significant expansion of calcium-silica gels is in contrast to the swelling with hydration of gels produced by the direct reaction of alkalies on siliceous aggregates, which gels contain a larger proportion of alkalies, little calcium, and have great expansive capacity (5). Alkalies incorporated in the complex calcium-silica gels apparently are not available for reaction on susceptible aggregate particles. Consequently, the net reduction in alkali concentration in the chemical test (reduction in concentration of sodium minus the concentration of potassium) is considered to be of major significance in evaluating the ability of the material to counteract alkali-aggregate reaction.

Reduction in Alkalinity:

Inasmuch as the alkalies react on the aggregate as hydroxides, the hydroxyl ion concentration is likewise important. The reduction in alkalinity (reduction in titratable OH^- ion) in the chemical test is somewhat greater for most pozzolans than the net reduction in total alkali concentration (reduction in concentration of Na^+ and K^+ ions). However, the two values parallel each other rather closely. Consequently, for the majority of pozzolans, determination of the reduction in alkalinity yields essentially the same information as does the reduction in concentration of sodium and potassium, with considerably less effort. However, anomalous results can be obtained for materials containing significant amounts of ferrous iron and magnesium carbonates, such as dolomite, siderite, and magnesite, which effect a reduction in alkalinity unrelated to reaction with sodium and potassium.

Dissolved Silica:

For most pozzolans, the amount of calcium hydroxide used in the test is in excess of that consumed in reactions, so that all but a small part of the silica released into solution is precipitated as a constituent of a complex gel. However, some materials, notably those containing much opal, release an excess of silica over that which can be precipitated by the calcium hydroxide present. This is illustrated in Table I, where the silica concentrations are shown to range from 0.4 millimole per liter for an argillaceous sandy silt calcined at various temperatures (samples Nos. 13, 15, 16, 18, 19, and 20) to 142 millimoles per liter for an opaline shale calcined at 1800 F (sample No. 33).

Silica found in solution at conclusion of the test, in excess of a few tenths of a millimole, would have been precipitated had sufficient calcium hydroxide been available, and additional sodium would have been removed from solution as part of the additional gel formed. Because of the difficulty, and sometimes impossibility, of obtaining enough filtrate for analysis in the procedures as established, it is impracticable to add sufficient calcium hydroxide to precipitate completely the silica released by the pozzolan. Consequently, for those pozzolans which release significant amounts of silica into solution under the conditions of the test, the reduction in alkali concentration actually determined could be modified by adding an increment dependent on the amount of silica in solution, this increment representing the further reduction in concentration of alkalies which would have occurred had the silica been precipitated completely as gel.

TABLE VIII.—RELATION OF PRECIPITATION OF ALUMINUM BY CALCIUM HYDROXIDE TO REDUCTION IN SODIUM CONCENTRATION.[a]

Weight of Aluminum Added,[b] g	Potential Aluminum Concentration,[c] me per liter	Actual Aluminum Concentration at End of Test, me per liter	Reduction in Sodium, me per liter
0.016	25	4.5	16
0.033	50	4.0	12
0.065	100	8.0	20
0.130	200	4.0	16
0.195	300	4.0	16

[a] Tests performed in accordance with procedure described in Appendix II, using indicated amounts of aluminum but no pozzolan.

[b] Aluminum hydroxide [$Al(OH)_3$] prepared by precipitation from aluminum chloride solution with ammonium hydroxide, followed by filtering, thorough washing, and drying.

[c] Concentrations of aluminum which would exist if aluminum added were all in solution at one time. It is recognized that actually the aluminum progressively dissolves and is precipitated by reaction with the calcium hydroxide.

Experiments in which various weights of amorphous silica were caused to react with 0.5 *N* sodium hydroxide and calcium hydroxide under the conditions of the test (Table VII) have demonstrated that the additional reduction in concentration of sodium resulting from complete precipitation of silica is of a low order and may be disregarded.

Furthermore, pozzolans which release significant amounts of silica into solution in the test already produce large reductions in alkali concentration, so that there is no difficulty in correctly recognizing their satisfactory alkali reactivity.

Dissolved Aluminum:

A few pozzolans, such as calcined kaolin, release considerable amounts of aluminum into a sodium hydroxide solution. This aluminum can be precipitated by calcium hydroxide in the same manner as can the silica. Aluminum concentrations are reported in Table I for some of the tested pozzolans. Because silica in solution depresses the solubility of aluminum to a small value, analysis for aluminum was made for those materials which release 4.0 millimoles per liter or less of silica into solution. Aluminum concentrations range from 0.1 milliequivalent per liter for opal (sample No. 62) to 250 milliequivalents per liter for a kaolin calcined at 1400 F (sample No. 52).

The amount of sodium removed from the solution by precipitation of aluminum by calcium hydroxide is even less than is accomplished by precipitation of the silica (Table VIII). Consequently, both silica and aluminum can be disregarded and the net reduction in total alkali (Na^+ and K^+) used as an index of alkali reactivity.

CONCLUSIONS

The ability of a pozzolan to control expansion of mortar resulting from alkali-aggregate reaction is indicated by a chemical test in which the net reduction in alkali concentration of a 0.5 N sodium hydroxide solution is determined after reaction with the pozzolan in the presence of calcium hydroxide. Results of the test correlate well with the mortar-bar test using Pyrex aggregate and high-alkali cement. Results may be obtained quicker and reproducibility is better than in the mortar-bar test.

A net reduction in alkali (reduction in concentration of sodium minus the concentration of potassium) of 180 milliequivalents per liter or greater indicates that the pozzolan will control the reaction between aggregates and alkalies released during hydration of portland cement. This value corresponds approximately to a reduction in expansion in the mortar-bar test of 75 per cent or more at 14 days.

For many materials, the reduction in alkalinity of the sodium hydroxide solution, determined by titration with standard hydrochloric acid, yields a satisfactory indication of alkali reactivity and is easier to obtain. A reduction in alkalinity of 210 milliequivalents per liter is approximately equivalent to a net reduction in alkali concentration of 180 milliequivalents per liter. Anomalous results appear for some materials in use of reduction in alkalinity.

The test is recommended for use in specifications covering the selection and control of pozzolans. The procedure can be performed and necessary analyses can be completed in two workdays.

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APPENDIX I

Special Apparatus and Reagents

Containers:

The reaction containers are of stainless steel, monel, or other nonreactive metal. They should be of not more than 50-ml capacity and should be provided with covers giving an airtight and watertight seal. The design of the container is illustrated in Fig. 3.

The method used to mold the Neoprene gasket in the cover of the container is as follows. A ring is cut from $\frac{1}{8}$-in thick uncured sheet Neoprene and fitted into the groove in the metal cover (segments of a ring will be suitable if the overlapping edges are beveled). A circular die is placed over the ring of Neoprene in the groove and clamped on as tightly as possible with a C-clamp. This assembly is placed in an electric oven and the Neoprene cured for 45 min at 295 F. The assembly is then removed from the oven and allowed to cool, and the clamp and die are removed.

The die used to mold the gasket consists of a piece of steel tubing, 2-in outside diameter, $1\frac{5}{8}$-in inside diameter, and 1-in long, on which a shoulder was cut so that a ring $\frac{1}{32}$-in high and $\frac{7}{64}$-in wide would project down into the groove in the cover. The $\frac{1}{64}$-in clearance allows excess Neoprene to escape from the groove. The material is removed with a razor blade after curing.

Constant Temperature Bath:

The bath must be large enough to hold the agitator assembly and be capable of maintaining a temperature of 80 ± 1 C. Figure 4 illustrates the bath used in the laboratories of the Bureau of Reclamation.

Agitator:

The agitator used in development of the test holds 20 containers and gives to them an end-over-end rotation of 30 rpm through a chain and gear system. The agitator is shown in place in the constant temperature bath in Fig. 4 and separately in Fig. 5.

Other Equipment:

1. Filtration assembly—Faucet aspirator connected through a trap to an open-top bell jar. Solution is filtered through a Buchner funnel into a 50-ml Erlenmeyer flask under the bell jar.

2. Titrating equipment—25-ml burette.

3. Spectrophotometer and flame photometer—The instrument used in development of the test was a Beckman Model DU spectrophotometer with flame photometer accessory.

Special Reagents and Solutions:

1. 0.500 ± 0.010 *N* NaOH solution freshly made from reagent grade NaOH and standardized to ± 0.001 *N* with standard 0.05 *N* HCl.

2. $Ca(OH)_2$, reagent grade.

3. HCl, 0.25 *N*.

4. HCl, 0.05 *N*, standardized to ± 0.0001 *N*.

5. HCl, 1:3 (approximately 3 *N*).

6. Ammonium molybdate solution, $(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$, reagent grade, 10 per cent in water.

7. Oxalic acid, reagent grade, 4 per cent in water.

8. HCl, 1:9 (approximately 1.2 *N*).

9. Ammonium aurin tricarboxylate solution (Aluminon), 0.2 per cent in water, laboratory prepared. (Commercial Aluminon is not satisfactory).

10. Ammonium acetate solution, $HN_4C_2H_3O_2$, reagent grade, 20 per cent in water.

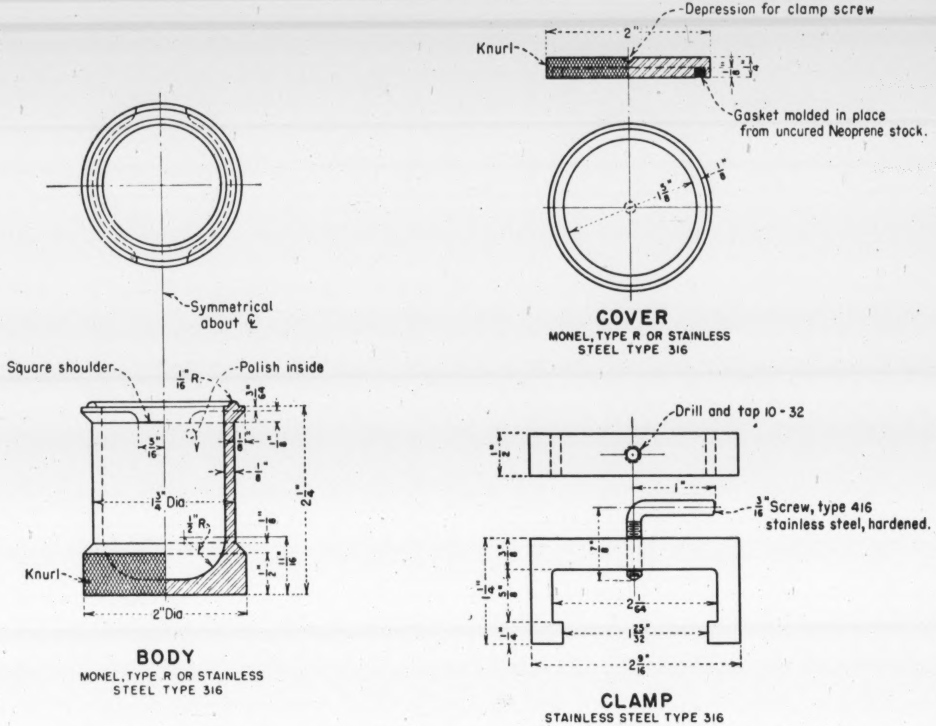
Depression for clamp screw
Knurl
2"
Gasket molded in place from uncured Neoprene stock.
COVER
MONEL, TYPE R OR STAINLESS STEEL TYPE 316
Symmetrical about ℄
Square shoulder
$\frac{1}{16}$" R
Polish inside
$\frac{5}{16}$"
$1\frac{3}{4}$" Dia
$\frac{1}{2}$" R
$\frac{1}{8}$"
$2\frac{1}{4}$"
Knurl
2" Dia
BODY
MONEL, TYPE R OR STAINLESS STEEL TYPE 316
Drill and tap 10-32
$\frac{1}{2}$"
1"
$\frac{3}{16}$" Screw, type 416 stainless steel, hardened.
$2\frac{1}{64}$
$1\frac{25}{32}$"
$2\frac{9}{16}$"
CLAMP
STAINLESS STEEL TYPE 316

FIG. 3.—Reaction Container Used in Chemical Test for Alkali Reactivity of Pozzolans.

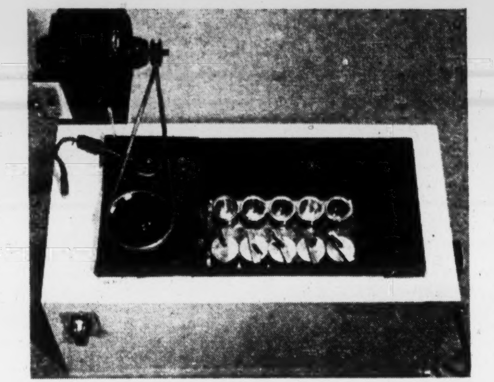

FIG. 4.—Constant Temperature Bath and Agitator Used in Chemical Test for Alkali Reactivity of Pozzolans.

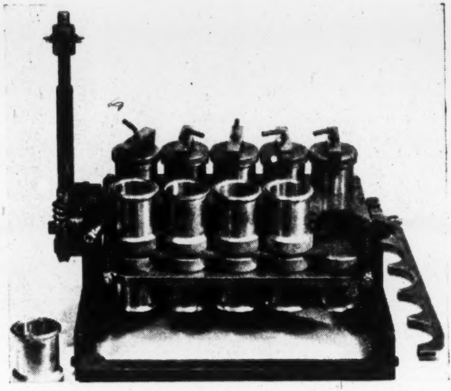

FIG. 5.—Agitator Mechanism Used in Chemical Test for Alkali Reactivity of Pozzolans.

APPENDIX II

TEST PROCEDURE

Reaction:

Weigh 4.00 g of pozzolan and 1.50 g of $Ca(OH)_2$ into each nonreactive metal container. Mix the dry materials thoroughly, then pipet 25 ml of the standardized 0.5 *N* NaOH solution into the container, seal, place in the agitator in the constant temperature bath, and maintain with continuous agitation at 80 ± 1 C for 24 hr ± 10 min. Remove from the bath, cool under tap water at 25 C for 15 min.

Filtration:

Open each container and decant the supernatant liquid into a dry Buchner funnel fitted with Whatman No. 1 filter paper and installed in the vacuum filter assembly so as to discharge into a 50-ml Erlenmeyer flask. Apply the vacuum and transfer the residue from the container into the funnel by means of a stainless-steel spatula and pack tightly in the filter. Continue to apply vacuum until less than one drop of filtrate in 30 sec falls from the funnel stem. Agitate the filtrate thoroughly by shaking and swirling the flask, withdraw 5 ml with a pipet, and place in a 100-ml volumetric flask. Dilute the aliquot to the mark with distilled water and store in a stoppered flask for analysis. This is hereafter designated as the "stock solution."

Sodium and Potassium Analyses:

Prepare a series of standard solutions of pure (reagent grade) sodium chloride having concentrations of 2.0, 1.5, 1.0, and 0.5 milliequivalents per liter. Pipet 5 ml of the stock solution into a 100-ml volumetric flask, add 1 ml of 0.25 *N* HCl, fill to the mark, and shake well. Determine the sodium concentration of this solution by comparing the flame emission intensity of the sodium lines at 589 mμ with that of the standard solutions by means of the flame photometer. (The exact procedure will depend on the type of instrument used.) The same general procedure and the same dilution of stock solution is used for determination of potassium except that the strongest standard solution need be only 1.0 milliequivalent per liter of KCl. If the concentration of potassium in the sample is appreciable, it may interfere with the determination of sodium. If the error is found to be serious, it may be compensated for by addition of the proper amount of KCl to the sodium standards or by interpolation from intensity *versus* concentration curves of sodium solutions containing various known amounts of potassium.

Titration:

Pipet a 20-ml sample of the stock solution into a flask suitable for titration and titrate to the phenolphthalein end point with 0.05 *N* standard HCl. Record the volume of acid used. The reduction in alkalinity equals C − 50V, where C is the concentration of the original 0.5 *N* NaOH solution in milliequivalents per liter, and V is the number of milliliters of 0.05 *N* HCl used in the titration.

Silica Analysis (Optional):

Pipet a 10-ml sample of the stock solution into a 100-ml flask, fill half full with distilled water, add 2 ± 0.05 ml of 10 per cent ammonium molybdate solution, then 1 ± 0.05 ml of 3 *N* HCl. After 5 min add 1 ± 0.05 ml of 4 per cent oxalic acid, fill to the mark, and immediately read the transmittancy with the spectrophotometer against a reference solution made up exactly as the sample but containing no portion of stock solution. (With the Beckman DU instrument, the details are as follows: wave length, 410 mμ; sensitivity, near clockwise limit; slit width, about 0.07 ml; phototube, ultraviolet sensitive (knob out); filter, none; cell type, Corex 10 ml.) A standard curve is prepared previously by plotting concentration of SiO_2 against transmittancy for various dilutions of an analyzed sodium-silicate solution in the range 0 to 0.5 millimole per liter of SiO_2; or, if preferred, 0.3003 g of pure quartz may be fused with 3 g of sodium carbonate (SiO_2 free), dissolved in distilled water, and diluted to 1 liter to give a solution containing 5.00 millimoles SiO_2 per liter. Several dilutions from this solution may be used to plot the standard curve. (Greater dilution of the stock solution than indicated may be necessary in order to make the transmittancy fall in the range covered by the standard curve.)

Aluminum Analysis (*Optional*):

Pipet 5 ml of the stock solution into a 25-ml volumetric flask, fill three-fourths full with distilled water, add 1 ml of 1.2 *N* HCl, shake, add 1 ml of 0.2 per cent Aluminon solution, shake well, and add 2.5 ml of 20 per cent ammonium acetate solution. Fill to the mark, mix well, and allow the red color to develop for 30 min. Prepare a reference solution in the same way, omitting the portion of stock solution. Compare the transmittancy of the sample solution with the reference solution in the spectrophotometer. (With the Beckman DU instrument, the details are as follows: wavelength, 530 mμ; slit width, about 0.04 ml; phototube, ultraviolet sensitive; filter, none; cell type, Corex 10 ml.) A standard curve of concentration of aluminum against transmittancy is prepared previously, using solutions of $AlCl_3$ in the range 0 to 25 milliequivalents of aluminum per liter. If the sample develops too intense a color or if precipitation occurs, the concentration of aluminum is too high and a greater dilution must be used.

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SIGNIFICANT FACTORS AFFECTING CONCRETE DURABILITY*

By C. H. Scholer[1]

For the past several years a major activity of the Subcommittee, of ASTM Committee C-9, on Durability of Concrete has been the preparation of a detailed outline of the various factors that may influence concrete durability. The complete tabular outline is appended to this paper. The factors were subdivided into five major groups:

1. The physical properties of the hardened concrete.
2. The constituent materials of which the concrete is composed.
3. The construction processes used in fabricating or building the structure.
4. The nature of the exposure to deteriorating influences to which the structure will be exposed.
5. The type of loads which the structure is designed to carry, and to which it will be subjected during its useful life.

Not all of these factors are of equal significance in their effect upon the durability of the concrete structures. Some are obviously of major importance; some are reasonably well understood, but many which might exert a major rôle in determining the life of the concrete have, to date, been almost entirely ignored.

In this paper the author will not attempt to discuss all of the some hundred items of the outline but will discuss those areas in which knowledge is, at present, most highly developed, and will attempt to find out the direction in which future research should trend.

Physical Properties of the Hardened Concrete

Certain of the physical properties of hardened concrete are highly significant in controlling the degree of weathering resistance which the concrete will be capable of withstanding. Concrete exhibits elastic and plastic properties. It has considerable strength—flexural and compressive—and is resistant to impact and attrition due to abrasion. Further, while concrete is elastic it is also slightly plastic, and under sustained loads some plastic flow is known to occur. Concrete expands with a rise in temperature and shrinks with a drop in temperature. As it loses moisture content, shrinkage occurs, and as moisture is added by absorption an increase in volume occurs. All concrete contains voids—air voids and water voids. Some of the water in these voids is in such a state that it is not freezable at natural temperatures, but some of the entrained water will always be freezable at temperatures below the normal freezing point that may readily occur in temperate and northern climates.

Most of our progress in predicting and controlling the probable durability of concrete has been in the field of air and water voids. Since the presentation of the first paper on freezing-and-thawing tests of concrete to the Society in 1928, a great many papers have been written upon the resistance to freezing and thawing of concrete and mortars, and the state of our knowledge relating to the effect of water content in hardened concrete and the air voids of that hardened concrete has reached a high stage of predictability. Our knowledge of air-entraining concrete and its effect upon the resistance of concrete to the disintegrating effects of freezing and thawing is well understood.[2] Although knowledge of the effect of entrained air upon concrete durability is fairly well advanced—probably the most advanced of any phase of knowledge of concrete durability—it is the author's belief that considerable work yet remains to be done. There is little information about the actual amount of air in the hardened concrete, most of the data being restricted to the air content of the green concrete. This matter is receiving some attention at this time and is probably well on the way to being solved rather satisfactorily.

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

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Damage to concrete by freezing and thawing is due to the pressure developed by the freezable water in the concrete as the water is gradually turned to ice. In addition to knowledge of air voids in concrete, information as to the water content of the hardened concrete and the percentage of water in a freezable form is necessary. Mr. T. C. Powers of the Portland Cement Assn. has developed significant information about the relation of water content of cement pastes to resistance to freezing and thawing. It is believed this information is adequate and satisfactory. As yet, there is no means of determining the water content of concrete in its hardened state. The actual water content incorporated and retained in the hardened concrete will vary due to the effect of construction practices, including finishing and curing, and later exposure to moisture. At present, no satisfactory means of measuring this has been developed. It is believed that many of the inconsistencies that develop in accelerated freezing-and-thawing tests are due to unknown variations of the actual water content of the hardened concrete. This subject merits further study.

The elasticity, plasticity, and thermal expansion of concrete may play an important part in the ultimate durability of a concrete structure. There is only fragmentary information about the effect of variations in the thermal characteristics of concrete aggregates and cement pastes and the interrelationship of stresses that may develop when these materials are formed into concrete. Thermal incompatibility has long been recognized as a possible important element in concrete durability. Most of the studies of thermal incompatibility have, to date, given almost no attention to the matters of plastic flow under stress and have given but little attention to the elastic properties of the materials involved. Thermal incompatibility cannot be studied satisfactorily without complete recognition of variations in elastic, plastic, and thermal properties of each of the constituents involved. Variations in elastic properties and possibly in plastic properties of hardened concrete are fully as great and fully as significant as are the variations in thermal properties. Since, in most instances of natural exposure, thermal stresses will develop rather slowly, it is almost certain that plastic flow offers material assistance in decreasing the severity of these stresses. The problem is further complicated by the fact that the thermal and elastic properties of portland-cement pastes and mortars are drastically affected by changes in moisture content. Consequently, in approaching any of these problems involving the effect of changes in elasticity, plasticity, and thermal incompatibility, steps must be taken at all times to insure that adequate control of the moisture in the specimens is also attained. It is believed that this field is one of the more important fields to which immediate attention should be directed.

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[2] "A Bibliography on Durability of Concrete, Physical Reaction," Highway Research Bibliography No. 8, 1951.

CONSTITUENT MATERIALS

Most of the studies of concrete durability have hinged about the effect of one or more of the major constituents of the concrete upon the concrete durability. As shown in the tabular outline, concrete is made with varying proportions of cement, air, water, fine aggregate, coarse aggregate, and admixtures. Since the one constituent which was man-made and over which there was a reasonable degree of control was the portland cement, a great many studies of concrete durability have centered about the cement and its characteristics. Recently the development of artificial aggregates and of certain admixtures by modern manufacturing processes have introduced new elements for the consideration of the men who are trying to evaluate concrete durability. Depending upon the thoroughness of the investigation and whether or not sufficient time was allowed for the adequate curing of the concrete involved in making the study, many erroneous conclusions have been reached in regard to the effect of portland cement upon concrete durability. It is the author's opinion after reviewing most of the published papers on this subject that concrete characteristics other than cement composition have been almost without exception the controlling factor in concrete durability in relation to freezing and thawing. After studying several thousand lane-miles of concrete pavement, involving a great many portland cements varying through all probable ranges of portland cement composition, no characteristic trend of certain types of cement and their effect upon concrete durability in relation to freezing and thawing was apparent. These conclusions were based upon actual concrete projects constructed in the field. Many years later, following "the long-time study test of concrete-cement performance," Mr. Jackson has reported that he finds in the field no apparent relationship between type of cement and the service rendered in the field. Most of the variations observed on structures actually built in the field where only physical effects are to be observed are due to variations in air and water content which may have been due to variations in the cement, fine aggregate, coarse aggregate, proportions, or construction practices. It will be noted that again the cement is included as one of the factors that may cause variations in the air and water content of the hardened concrete and consequent variations in the ability of this concrete to resist freezing-and-thawing exposure. The author very clearly recalls when Mr. Bert Meyers of the Iowa State Highway Commission at a meeting of the Highway Research Board many years ago, told of his experience in trying to rate cements according to the resistance which they offered to freezing and thawing and according to some other important concrete characteristics. Using a given combinations of aggregates, Mr. Meyers prepared the specimens and subjected them to the various tests from which he was able to rate the cements in the order of performance from best to poorest. He then decided to rate the performance of the aggregates. He found that, depending upon which cement he used, he could arrange the aggregates in many ways; depending upon which aggregates he used, he could rearrange the cements according to their performance in many different combinations. This again illustrates the extreme difficulty of trying to evaluate any one constituent material and its effect upon concrete performance when the other materials are varied. These variations affect many of the characteristics of hardened concrete. The air and water voids will change if either the cements or the aggregates are changed. Depending upon construction practices and methods of curing, the air and water voids may be varied even though cement and aggregates are the same. The timing of finishing and curing operations has a controlling effect upon the air and water voids in the surface which is being finished. It will be noted how important it is that the characteristics of the hardened concrete, particularly in relation to air and water voids, must be controlled if the resulting durability tests are to be of adequate significance.

Cement:

Portland cement is a very complicated product, and considering the extremely wide variation in raw materials and manufacturing processes, it has, after all, rather uniform general characteristics and utility. Probably every one of the items mentioned under the heading "cement" in the outline appended to this report have some effect upon the type of service a cement will render. But these are so interrelated with characteristics other than the so-called cement characteristics that it is actually very difficult to measure the significance of certain changes in the portland cement composition, methods of burning, grinding, etc. The outline mentions 23 different items that may affect a portland cement. On most of these items our information regarding the significance of changes in cement composition, methods of burning, and fineness of grinding are very inadequate. Two cements identically the same in oxide composition, including the alkalies and other so-called minor constituents, ground to the same degree of fineness and incorporated into the concrete, may produce concrete exhibiting radically different characteristics in regard to its resistance to disintegration by freezing and thawing or by chemical reaction between cement and aggregate or by the action of aggressive waters.

It is generally believed, and numerous tests have demonstrated, that the finer the grinding of a given clinker the more rapid the rate of strength development in mortar or concrete. Nevertheless, only recently a competent cement manufacturer made a study of the strengths shown by his product over a rather extended period and found but little correlation between strength and fineness of grinding. Other factors not generally understood or measured were sufficient to obscure these usually significant variables. It is not unusual to find one reputable and experienced manufacturer of portland cement who will claim that for controlling strength he finds he must control the fineness of his cement by means of the Wagner apparatus. Another equally experienced and reputable manufacturer of portland cement will advise that he must control the fineness of his product by means of the Blaine apparatus. As long as we have so much difficulty in actually determining such a relatively simple thing as fineness of portland cement and its effect upon strength characteristics of the resulting cement, it is not surprising to find that there is but little relationship between the chemical composition of portland cements as manufactured under the current ASTM specifications and the little understood characteristics of the concrete which these cements produce in a concrete. Some of these characteristics are determining factors of durability.

The chemical composition of portland cement can be used as a control over the probable reaction of concrete in sulfate water and, with a fair degree of success, for the control of the chemical reaction between cements and aggregates. Where heat of hydration of the cement may cause undesirable variations in the resulting temperatures of the concrete as it is placed, this item is of extreme importance and can be controlled by composition, but this affects only mass concrete construction. The oxide composition of a cement is as yet of little value in predicting the probable performance of a concrete in which the cement is to be used. The standard physical tests have no relationship to final durability unless the cement has been given air-entraining characteristics by the use of a suitable addition.

Fine Aggregate:

Next to portland cement, probably the characteristics of the fine aggregate have the most profound effect upon the characteristics of the hardened concrete. In spite of this, knowledge of the effect of the fine aggregate upon the resulting durability of concrete produced with this fine aggregate is very fragmentary. Fine aggregates are produced having almost every conceivable variation in mineral composition that may occur in the natural rocks from which these sands were formed. It has not, however, been possible to demonstrate effectively, except in the case of a few highly deleterious materials such as certain shales, opal, and glassy volcanic rocks, that the composition of the sand has very much to do with the final characteristics of the hardened concrete. Variations in particle shape, surface characteristics of the particles, and gradation of these particles will have considerable effect upon the water content required to produce a concrete of satisfactory characteristics and consequently upon the final air content and water content of the hardened concrete. Almost universally sands are used which are known to be markedly deficient in the quantity of fines to give the best characteristics as regards workability and water requirements. However, there are no commonly accepted tests which can be used to demonstrate that the better graded sands offer enough improvement over the ordinary gradation of sand used to justify the increased expense. The experience of the Army Corps of Engineers in producing artificial sands with a very high degree of controlled gradation and particle shape would seem to indicate that this might be a very desirable field of investigation leading to the production of more durable concrete. The excellent results they have secured in freezing-and-thawing tests are most encouraging. Although in most published papers on the subject the writers have emphasized the thermal compatibility of such aggregates as being one of the major factors in producing better concrete, the more desirable characteristics of the mortars produced by the well-controlled grading cannot be overlooked.

Of the more abstract characteristics of sand, such as resistance to freezing-and-thawing tests or magnesium or sodium sulfate solutions, there is little information. There is no question but that certain sands which have been used for many years in some sections of the country have tended to produce poor concrete with inadequate resistance to freezing and thawing. Whether or not these characteristics were related to the low resistance these sands offered to sodium sulfate or magnesium sulfate solutions is not certain. With adequate air-entrainment, concretes made with such sands have offered excellent resistance to weathering for some 10 years or more. Structures made with such sands have been observed in excellent condition after over 30 years of weathering exposure in severe climates when used with certain cements. Whether or not the particular relationship between air content and water content in these few isolated cases is responsible for the good service record, it is impossible to state.

With the development of information indicating that the alkalies of the cements react with certain mineral constituents of the fine aggregate in particular, later causing injurious expansion and loss of strength in the concrete, another variable in fine aggregate characteristics was introduced. The present tentative method of test for potential reactivity of a cement-aggregate combination may be depended upon for guidance with high-alkali cements.[3] Much data in the author's studies indicate that it will not reveal potential activity with medium or borderline alkali content cements. There can be no question but that sand containing opal and certain other mineral constituents which react with alkaline solutions may be injurious to concrete. The present test requirements for determining cement aggregate reactivity are very helpful. It is believed that these requirements are not entirely dependable, and do not insure that sands which meet them are acceptable for use. In most cases involving the possibility of adverse cement-aggregate reaction, present tests will indicate the more violent reactions. The tests will not discriminate between borderline cases which so frequently arise. A more critical test is desirable.

Coarse Aggregate:

The largest volume of any single material in a typical concrete is the coarse aggregate, and most specifications for coarse aggregate specify nothing of particular importance regarding the performance of the coarse aggregate in concrete. Coarse aggregate characteristics are undoubtedly of extreme importance in concrete performance, and it is time that more serious consideration be given to the specifications for this major constituent in concrete. The outline of the characteristics of coarse aggregates that may affect concrete durability lists some 30 characteristics that may be of importance.

Coarse aggregate, in general, exhibits physical properties comparable with those of the hardened concrete. The modulus of elasticity, thermal coefficient of expansion, and plastic flow of the concrete are most profoundly affected by the coarse aggregate. Most coarse aggregates contain more or less deleterious material, and more or less materials unsatisfactory in soundness under freezing and thawing or the action of sodium or magnesium sulfate. There is but little information about the effect of variations in the quantity of questionable material. The limits as to the quantities of these questionable materials are usually established by the practicability of securing a material from a given source having as little of this injurious material as possible. In some instances this unsoundness may seriously affect the soundness of the concrete. In other instances it will have but little effect upon the soundness of the concrete, unless the unsound material is used in quantities much larger than most limits permit. Nevertheless, an engineer who is forced to use as a source of material coarse aggregates containing appreciable quantities of unsound material finds but few test data to substantiate any conclusions he may draw. Better and more rigorous investigations of these matters are needed and more accurate information as to the effect of this on the ultimate concrete produced by some of these deleterious materials found in coarse aggregate. Methods of beneficiation of coarse aggregates by eliminating certain undesirable constituents are being developed. This item needs to be vigorously investigated.

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[3] Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227–51 T), 1951 Supplement to Book of ASTM Standards, Part 3, p. 13.

If unsatisfactory material will of necessity occur in a source of coarse aggregate, the larger the particles the more objectionable they will be. In such cases the maximum size can frequently be reduced to advantage. Where heat of hydration and volume change due to variation of cement content are of extreme importance, large-size coarse aggregate is definitely indicated. Where heat of hydration is not important, as in pavements and a great many other concrete structures, there are certain very definite objections to the use of the large-size coarse aggregate that is commonly specified. There is needed more study of the effect of maximum size of coarse aggregate upon the weathering resistance of concrete, particularly where freezing and thawing and the problem of so-called thermal incompatibility are present. In freezing-and-thawing tests, all of which would accentuate thermal incompatibility if it existed, the most critical type of disintegration is the loss of bond of mortar to the coarse aggregate and the consequent disintegration of the concrete mass. The larger the coarse aggregate the more critical this tendency for loss of bond becomes. Since most freezing-and-thawing tests of concrete are made on rather small-size test specimens, there is little added to our knowledge of what the optimum maximum size is for coarse aggregate in various types of concrete construction. If incompatibility of the elastic properties, thermal properties, and plastic properties of the concrete are important, the coarse aggregate will be a major factor in determining the incompatibility of the ingredients of any concrete mixture.

An examination of concrete which shows bad weathering characteristics tends to indicate that frequently the surface characteristics of the coarse aggregate may have been an important factor in limiting the ability of the concrete to resist the disintegrating effects of weather. There is no information about the value of the mortar bond to the various types of surface presented by the fractured face of a piece of crushed stone or the polished face of weathered gravel. To any one who has observed many structures in their various stages of weathering deterioration, all of these elements seem to demand an answer to the question of how this characteristic affects the concrete durability. Little progress is being made.

Although the total surface of the coarse aggregate in a given concrete mixture is small compared with the surface of a fine aggregate concrete mixture, it is reasonably certain that where the mineral composition of the coarse aggregate is such that it will react with the constituents of a portland cement to produce internal expansion, cracking, and loss of strength, it should be used with extreme caution. Some instances are known in which such aggregate has been successfully used in a concrete structure, and in other instances it has caused serious deterioration in a comparatively few years. Present tests for cement-aggregate reaction are nearly all based upon the use of mortars. Tests of the whole concrete should be developed, as it is reasonably certain that every element in the concrete mixture affects the stability and permanence of the resulting mass.

CONSTRUCTION PRACTICES

That construction processes and practices may have a great influence upon the final quality of the concrete produced is conceded by all engineers. Data substantiating this thought is almost nonexistent. All are interested in good construction practices, but these are, at times, very difficult to attain, and the evil results of bad practices are hard to demonstrate.

Granting that aggregates and cement are properly prepared and brought to the plant for mixing, much may happen to cause deterioration or develop nonuniformity in the materials.

Improper stock piling and handling of aggregate may substantially change the grading of the material through breakage and segregation. This will cause a nonuniformity in the consistency of the resulting concrete and produce objectionable variations in air and water content.

The chief errors of which we are aware in construction are those which affect the final air and water content of the concrete, and thus its durability. Studies of these variations and their significance are sadly lacking.

Curing of concrete which implies both temperature and water control during the hardening period is supposed to be vitally important. The few studies of field curing are sadly lacking in facts with which to demonstrate the importance of good curing. The general conception that curing by keeping the concrete saturated, if not submerged during its early life, is the best curing, is based almost entirely upon laboratory tests which show that the highest compressive strength will be attained by concretes so cured. That the greatest durability will be secured by such curing is an open question.

In the author's opinion the question what constitutes properly cured concrete has not yet been answered. It is not unlikely that, depending upon the future use of the concrete and the type of structure being built, curing practices should be rather widely varied.

From every consideration, it is desirable to have closer collaboration and cooperation between laboratory and field observations if there is to be improvement in our knowledge of construction practices and their effect upon the durability of the concrete produced.

NATURE OF THE EXPOSURE AND TYPE OF LOADING

Concrete is used in every conceivable climatic and natural exposure condition. Although our observations of concrete deterioration indicate that most of the difficulty develops in areas where extreme range of temperature and moisture content occur, concrete which is exposed to almost constant moisture and temperature conditions also gets into trouble. In trying to evaluate the relative durability of a concrete structure, great care must be exercised in ascertaining the relative intensity of the various degrees of exposure to the natural weathering conditions which the concrete has received. It is by no means easy to ascertain the relative severity of exposure of two adjacent structures or of portions of the same structure. The water content of foundations on which the surface rests, or the character of backfill and natural drainage to a given abutment or retaining wall may vary 100 per cent in the distance of only a few feet. The author has observed railway drainage structures in which one abutment was under a considerable head of water on the back where the open ballast brought in water for several thousand feet, while the opposite abutment was dry because drainage was from the structure on that side. Due to changes in soil characteristics and the geological formation involved, subgrade under a pavement may change in only a few feet.

Where naturally alkaline drainage is involved, the character and amount of water to which concrete may be exposed can change very suddenly, from nondestructive conditions to a strength of solution that is destructive.

Effect of loads and traffic are difficult to estimate where deteriorating concrete is subjected to these loads and to traffic. As the strength and abrasive resistance of the concrete decreases, the apparent action is accelerated by the action of the loads. Perhaps the nature of the support, such as the subgrade beneath a concrete pavement which is pumping is changing, and over-stressing with the possible element of fatigue or fracture may be a confusing factor.

Exposure in Accelerated Tests:

When accelerated weathering tests are used, unknown factors are immediately introduced. The exposures to which the concrete is subjected are necessarily accentuated in order to secure more rapid results. In freezing-and-thawing tests usually the frequency of its temperature change is increased, and also the range of temperature changes. The rate of temperature change may be further speeded up by means of rapidly moving air or by the use of flowing water or freezing media. In order to get quick results, probably the exposure tests will be started at a much earlier age than is usually encountered in service. All of these factors tend to increase the effect of thermal incompatibility if its exists and to minimize the advantage of plastic flow if it were given time to act, and perhaps reduce the severity of shock due to sudden temperature changes.

Engineers are now evaluating the relative durability under freezing and thawing of batches of concrete before the concrete is even 90 days of age. The results may be of significance or they may be misleading.

The practice of placing field specimens matching the specimens tests in the laboratory for later observation is now becoming rather common. Such practice is very commendable, but it entails a great deal of work. Again, the severity of exposure will be extremely variable, and to enable engineers to correlate properly field exposure tests with laboratory results will require many specimens and great foresight. In 1937, at the time when the autoclave requirements for cement were being incorporated in the specifications for portland cement, the author was disturbed by the fact that no actual examples of concrete made with cement having a high autoclave expansion were being studied. No one knew what would be a suitable limit for permissible expansion. Accordingly, at considerable expense, and with excellent cooperation from cement manufacturers over the country, cements having a wide range of autoclave expansion were secured. These were combined into field concrete specimens and results awaited.

Unfortunately, the sand used was rather reactive sand, and now after 18 years of exposure, the results are vitiated by the fact that alkali aggregate reaction has developed, and it is impossible to determine what caused the expansion where it occurred.

The author believes that all research in the field of cement and concrete durability should have a good series of field specimens for outdoor exposure.

Concrete is one of the more durable materials, and some one should plant a garden for our children to enjoy and profit by.

The effect of coarse aggregate upon the alkali-aggregate reaction has been virtually ignored, but tests and experience indicate that some coarse aggregates delay, at least for many years, the expansive effects of this action and perhaps definitely inhibit the action. The real performance of such concrete can only be measured in the field.

In conclusion, it is the author's belief that most of the progress over the past twenty-five years in producing better concrete consists of discovery

1. That the air and water voids of the hardened concrete exert a controlling influence over its resistance to freezing-and-

thawing action. That the presence of 6 to 12 per cent, by volume, of air in the mortar portion of a concrete mixture is needed to secure adequate durability against freezing and thawing.

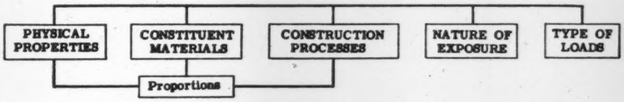
2. That aggregates are not chemically inert materials bonded together by an inert cement gel to form what we call concrete. Some of these aggregates are susceptible to reaction with the soluble alkalies of the portland cement. These reactions may set up destructive expansive forces in the concrete mass causing volume change and loss in strength.

3. That in mass concrete construction it is desirable to use a minimum of the cementing medium, consistent with adequate strength, to reduce the heat of hydration and resulting volume change during the early life of the structure.

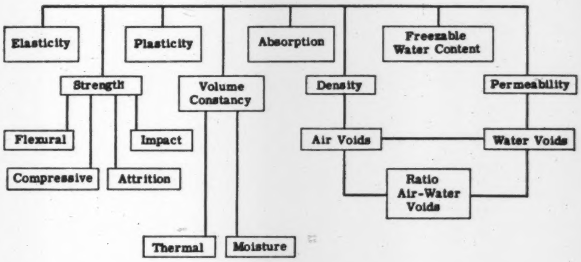
Much research is yet needed. Most of the items in the outline appended may well exert an influence on concrete durability. This effect may come from the particular property or material under consideration or by its indirect effect upon other elements which, in turn, affect the more critical variables of concrete durability.

Looking back on nearly thirty years of study of concrete and its component materials, the author is not too disturbed. He is impatient, but confident that highly significant progress is being made in the art of producing better concrete.

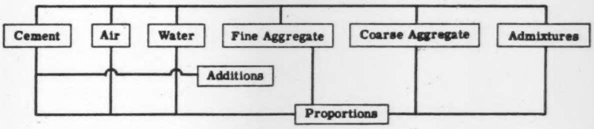
SOME FACTORS THAT MAY INFLUENCE CONCRETE DURABILITY


PHYSICAL PROPERTIES
CONSTITUENT MATERIALS
CONSTRUCTION PROCESSES
NATURE OF EXPOSURE
TYPE OF LOADS
Proportions

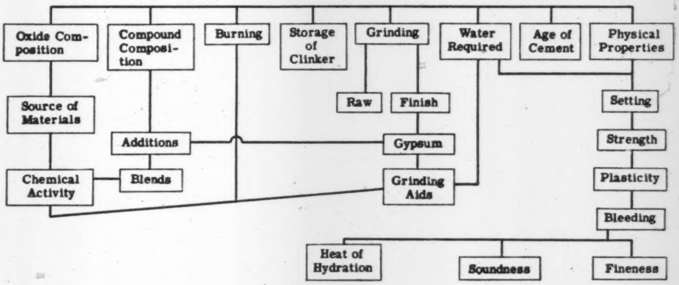
PHYSICAL PROPERTIES OF THE HARDENED CONCRETE


Elasticity
Plasticity
Absorption
Freezable Water Content
Strength
Volume Constancy
Density
Permeability
Flexural
Impact
Compressive
Attrition
Air Voids
Water Voids
Ratio Air-Water Voids
Thermal
Moisture

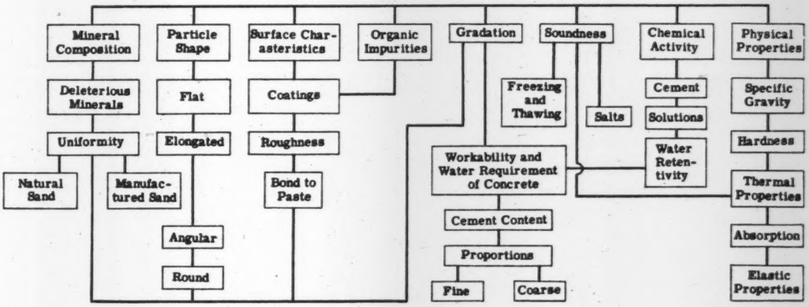
CONSTITUENT MATERIALS


Cement
Air
Water
Fine Aggregate
Coarse Aggregate
Admixtures
Additions
Proportions

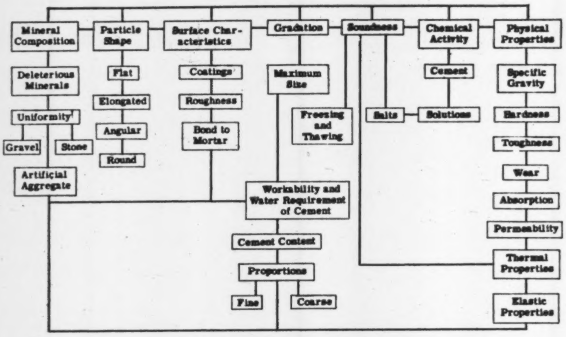
Cement


Oxide Composition
Compound Composition
Burning
Storage of Clinker
Grinding
Water Required
Age of Cement
Physical Properties
Source of Materials
Raw
Finish
Setting
Additions
Gypsum
Strength
Chemical Activity
Blends
Grinding Aids
Plasticity
Bleeding
Heat of Hydration
Soundness
Fineness

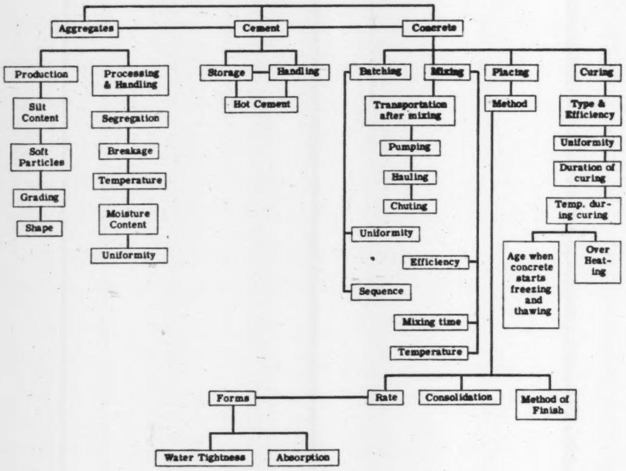
Fine Aggregate


Mineral Composition
Particle Shape
Surface Characteristics
Organic Impurities
Gradation
Soundness
Chemical Activity
Physical Properties
Deleterious Minerals
Flat
Coatings
Freezing and Thawing
Salts
Cement
Solutions
Specific Gravity
Uniformity
Elongated
Roughness
Water Retentivity
Hardness
Natural Sand
Manufactured Sand
Bond to Paste
Workability and Water Requirement of Concrete
Thermal Properties
Cement Content
Angular
Absorption
Proportions
Round
Fine
Coarse
Elastic Properties

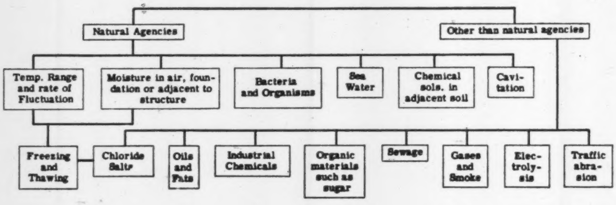
Coarse Aggregate


Mineral Composition
Particle Shape
Surface Characteristics
Gradation
Soundness
Chemical Activity
Physical Properties
Deleterious Minerals
Uniformity
Gravel
Stone
Artificial Aggregate
Flat
Elongated
Angular
Round
Coatings
Roughness
Bond to Mortar
Maximum Size
Freezing and Thawing
Salts
Cement
Solutions
Specific Gravity
Hardness
Toughness
Wear
Absorption
Permeability
Thermal Properties
Elastic Properties
Workability and Water Requirement of Cement
Cement Content
Proportions
Fine
Coarse

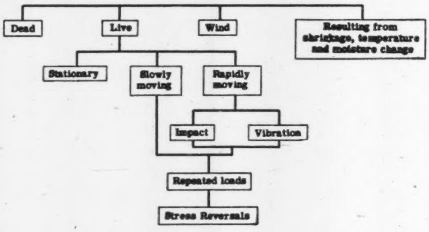
CONSTRUCTION PRACTICES


Aggregates
Cement
Concrete
Production
Processing & Handling
Silt Content
Soft Particles
Grading
Shape
Segregation
Breakage
Temperature
Moisture Content
Uniformity
Storage
Handling
Hot Cement
Batching
Mixing
Placing
Curing
Transportation after mixing
Pumping
Hauling
Chuting
Uniformity
Efficiency
Sequence
Mixing time
Temperature
Method
Type & Efficiency
Uniformity
Duration of curing
Temp. during curing
Age when concrete starts freezing and thawing
Over Heating
Forms
Rate
Consolidation
Method of Finish
Water Tightness
Absorption

NATURE OF EXPOSURE


Natural Agencies
Other than natural agencies
Temp. Range and rate of Fluctuation
Moisture in air, foundation or adjacent to structure
Bacteria and Organisms
Sea Water
Chemical sols. in adjacent soil
Cavitation
Freezing and Thawing
Chloride Salts
Oils and Fats
Industrial Chemicals
Organic materials such as sugar
Sewage
Gases and Smoke
Electrolysis
Traffic abrasion

TYPES OF LOADS


Dead
Live
Wind
Resulting from shrinkage, temperature and moisture change
Stationary
Slowly moving
Rapidly moving
Impact
Vibration
Repeated loads
Stress Reversals

DISCUSSION

Mr. Bryant Mather[1] (*by letter*).—Mr. Scholer states that our knowledge of the effect of the fine aggregate upon the resulting durability of concrete produced with this fine aggregate is very fragmentary. He also notes that variations in particle shape, surface characteristics, and grading will have a considerable effect upon water content and consequently upon the final air content and water content of the hardened concrete.

The writer would like to call attention to an interesting and very suggestive series of observations presented briefly by Mrs. Mather in her paper "Applications of Light Microscopy in Concrete Research."[2] She reports studies of samples of concrete taken from four dams. The essential characteristics of these concretes are as follows:

	Water-Cement Ratio, by weight	Actual Cement Factor, bags per cu yd	Fine Aggregate, per cent by weight of total aggregate	Aggregate Finer than No. 200 Sieve, per cent of fine aggregate	Nature of Aggregate	Cement
Dam A	0.51	3.9	26	4.8	Limestone	Type II
Dam B	0.59	3.8	26	8.1	Limestone	Type II
Dam C	0.54	3.9	24	3.2	Granodiorite	Type II
Dam D	0.56	3.8	26	3.2	Diorite	Type II

The limestone fine aggregates were reported, from field tests of grading, to contain more −200 material (on the average for the two projects, twice as much) as did the siliceous aggregates. In addition, it may be expected that there was even more −200 material produced during mixing and handling the concrete and that the additional fines so produced would be about 1.8 times as great in amount from the limestone aggregate as from the siliceous aggregate. The limestone-aggregate concretes were found to have relatively small calcium hydroxide crystals while the siliceous-aggregate concretes had relatively large crystals. The siliceous-aggregate concretes had larger areas of cement hydrate gel uninterrupted by fine crystalline particles of aggregate or calcium hydroxide than did the limestone-aggregate concretes. Limestone-aggregate concrete B, with the largest amount of finely divided crystalline material, showed the greatest development of cracks; concrete A, also with a relatively large amount of such material, showed considerable cracking, but less than B; siliceous-aggregate concretes C and D showed less cracking than A or B.

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[1] Engineer, Concrete Research Division, Waterways Experiment Station, Corps of Engineers, U. S. Army, Jackson, Miss.

[2] Symposium on Light Microscopy, Am. Soc. Testing Mats. (1952). (Issued as separate publication *STP No. 143.*)

The possibility that elastic properties and cracking tendency of concrete are related in a significant degree to fine aggregate grading and that the amount or type of −200 material exerts a significant control on the crystal size of calcium hydroxide produced in cement hydration suggests most interesting avenues for research in concrete durability.

CORRELATION OF SODIUM SULFATE SOUNDNESS OF COARSE AGGREGATE WITH DURABILITY AND COMPRESSIVE STRENGTH OF AIR-ENTRAINED CONCRETE*

By C. A. Vollick[1] and E. I. Skillman[1]

Synopsis

Coarse aggregates from 70 different sources were subjected to five cycles in the sodium sulfate soundness test. The same aggregates were also used to fabricate 3 by 6-in. cylinders of air-entrained concrete having uniform grading and water-cement ratio. One half of the cylinders were tested for 28-day compressive strength and one half were subjected to alternate cycles of freezing and thawing until 25 per cent of the original weight was lost from deterioration of the specimens. The test results were studied from the standpoint of relationships between the principal variables: sodium sulfate soundness, freezing-and-thawing durability, compressive strength, and cement content.

Accelerated soundness tests, involving the use of sodium or magnesium sulfate, have been used extensively to estimate the ability of concrete aggregate to withstand disruptive forces of freezing and thawing. Procedures and techniques in performing the sulfate soundness test have varied at different times and with different organizations. Contradictory results have been obtained by different applications of standard methods, and different interpretations have been placed on results.

The sodium sulfate soundness test was adopted by the Bureau of Reclamation in 1934 as a standard acceptance test for concrete aggregate. The method of test is patterned after ASTM Method C 88 - 46 T.[2] Automatic freezing-and-thawing equipment capable of holding 800 3 by 6-in. cylinders was installed in the Denver laboratory in the Spring of 1947, and a standard acceptance test for concrete aggregate, based on resistance to freezing and thawing of concrete made with the aggregate to be tested, was adopted by the Bureau of Reclamation in 1948. This report analyzes the data obtained from 70 different sources of coarse aggregate which have been tested since 1948. The influence of fine aggregate, minus No. 4 size, is not included in this discussion, because many coarse aggregate samples were combined with the same sand to make the concrete specimens.

Test Results

The test results were analyzed for all of the concretes, which contained 475 to 744 lb of cement per cu yd, and were compared with the sulfate losses of the coarse aggregates, which varied from 0.5 to 49.4 per cent. A comparison of the relationship between the sulfate loss of coarse aggregate and the freezing-and-thawing durability is shown in Fig. 1. The results of the statistical analysis are as follows:

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Material Engineers, Bureau of Reclamation, Denver, Colo.

Number of tests	70
Average sulfate loss, per cent	11.0
Average number of cycles of freezing and thawing	740
Correlation coefficient	—0.471
Standard error of estimate (cycles of freezing and thawing)	232

The correlation coefficient is "highly significant," and approximately two thirds of all test results should fall within the limits of the standard error of estimate as shown in Fig. 1. Examination of Fig. 1 indicates, however, that the durability of air-entrained concrete at a constant water-cement ratio is influenced by other factors that are not measured by sodium sulfate soundness test of the coarse aggregate.

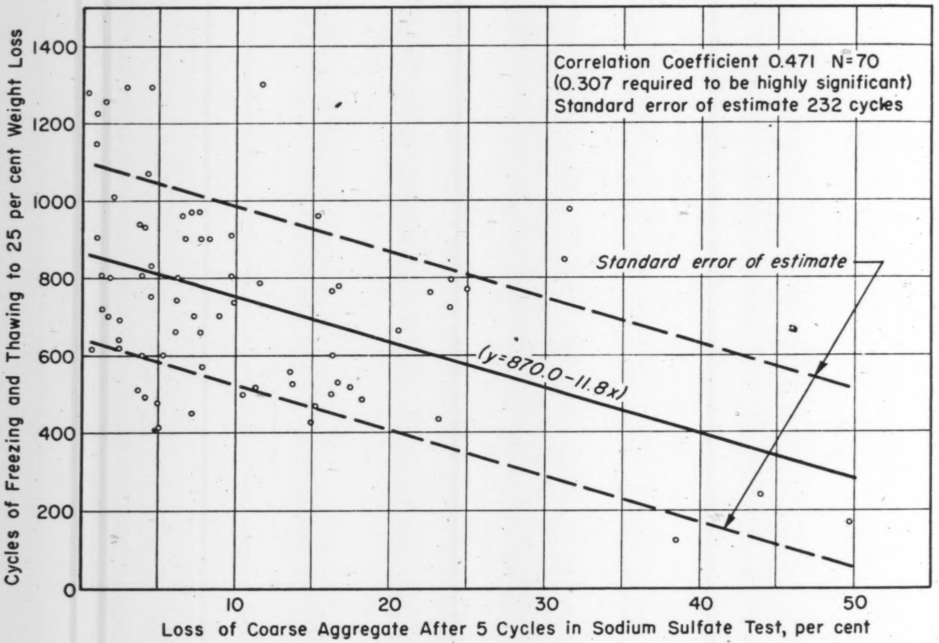
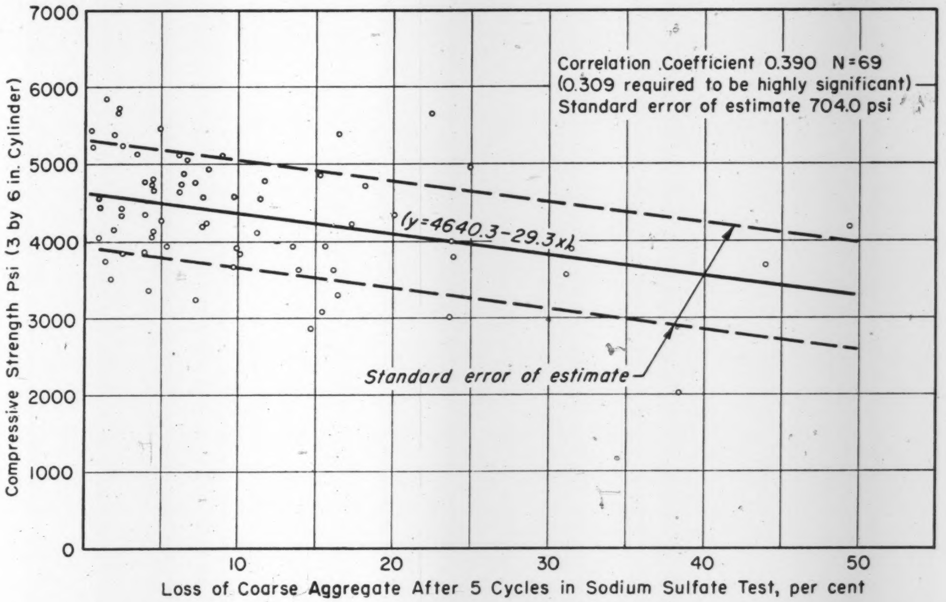


FIG. 1.—Correlation Between Loss of Coarse Aggregate in Sodium Sulfate Test and Freezing-and-Thawing Durability of Air-Entrained Concrete.

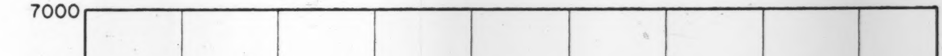
Inasmuch as the cement content of the concretes varied from 475 to 744 lb of cement per cu yd, the correlation between cement content of the concrete and the freezing-and-thawing durability of that concrete was investigated. This correlation was not found to be significant. The analysis of 70 tests showed the correlation coefficient to be only 0.076, with 0.236 required to be significant.

Service records of air-entrained concrete made with the 70 aggregates examined are not available. However, examination of the concrete in several Bureau of Reclamation dams that have been in service many years and comparison with freezing-and-thawing test results has led to the conclusion that concrete can be expected to give satisfactory service in field structures if it withstands 500 cycles of freezing and thawing in the standard Bureau of Reclamation laboratory test. Examination of Fig. 1 shows that in the majority of cases air-entrained concretes can be expected to withstand 500 cycles of freezing and thawing if the



Correlation Coefficient 0.390 N=69
(0.309 required to be highly significant)
Standard error of estimate 704.0 psi

FIG. 2.—Correlation Between Loss of Coarse Aggregate in Sodium Sulfate Test and Compressive Strength of Air-Entrained Concrete.



Correlation Coefficient 0.450 N=69
(0.309 required to be highly significant)
Standard error of estimate 683.0 psi

FIG. 3.—Correlation of Cement Content and Compressive Strength of Air-Entrained Concrete.

coarse aggregate does not lose more than 32 per cent in the sodium sulfate soundness test.

The compressive strength of 3 by 6-in. cylinders fabricated from 69 of the 70 mixes was also determined as part of the standard freezing-and-thawing acceptance test for aggregate, and a study was made of the relationship between compressive strength of the concrete and the sodium sulfate loss of the coarse aggregate. The results are plotted in Fig. 2. The correlation coefficient was calculated as in the case of the durability study, and the results are shown in the following tabulation:

Number of tests	69
Average sulfate loss, per cent	11.1
Average compressive strength, psi	4337
Correlation coefficient	−0.390
Standard error of estimate, psi	704

The correlation coefficient indicates a highly significant trend inasmuch as only 0.309 is required for "high significance."

The correlation between the cement content and the compressive strength of the 69 samples of concrete was also computed and showed a "highly significant" trend. The results are as follows (See Fig. 3):

Number of tests	69
Average cement content, lb per cu. yd.	588
Average compressive strength, psi	4330
Correlation coefficient	0.450
Standard error of estimate, psi	683

Inasmuch as the above analysis indicated that the strength of the concrete was influenced by the cement content of the concrete, it was considered advisable to determine if the relationship between sulfate loss of the coarse aggregate and strength of the concrete was due to the difference in cement requirement. The analysis of 70 tests showed the correlation coefficient was only 0.112, which is not considered significant. Apparently, the compressive strength of the concrete is influenced by the quality of the coarse aggregate, as measured by the sodium sulfate soundness test, and is also influenced by the cement content of the concrete.

MATERIALS AND PROCEDURES

Sodium Sulfate Soundness Test:

The method used by the Bureau of Reclamation for the sodium sulfate soundness test is based in general on ASTM Method C 88 – 46 T,[2] with the following differences:

(*a*) The maximum-size aggregate used by the Bureau is 1½ in., but for this correlation only ¾-in. maximum size aggregate was used.

(*b*) Earthenware containers were used both for storing the sodium sulfate solution and for holding the samples under test.

(*c*) The weight of the test fractions and the grading of the sand and gravel were as follows:

Particle Size	Typical Grading, per cent	Weight of Test Fractions, g
SAND		
No. 4 to 8	20	100
No. 8 to 16	20	100
No. 16 to 30	30	100
No. 30 to 50	30	100
Total	100	400
GRAVEL		
¾ to ⅜ in.	60	500
⅜ in. to No. 4	40	100
Total	100	600

(*d*) The controlled temperature and humidity room was maintained at 70 ± 2 F and 100 per cent relative humidity prior to May 1, 1950. At that time the controlled temperature was increased to 73 ± 2 F. This higher temperature affected approximately 4 per cent of the samples used in this correlation.

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[2] Tentative Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate (C 88 – 46 T), 1949 Bock of ASTM Standards, Part 3. p. 776.

Freezing-and-Thawing Concrete Durability Test:

Seventy different aggregates, listed in Table I, having losses in five cycles of sodium sulfate varying from 0.5 to 49.4 per cent, were combined with 48 different sands having losses in five cycles of sodium sulfate ranging from 0.8 to 16.8 per cent. Where crushed coarse aggregate or coarse aggregate without corresponding sand was being considered for use on a project, sand obtained from the vicinity of the laboratory was used in making concrete for the durability test. For this reason, the effect of sand upon durability, strength, and other properties of the concrete could not be analyzed. The sand samples containing excessive amounts of silt were washed.

Each sample of natural aggregate was screened into the nominal sizes ranging from $\frac{3}{4}$-in. maximum size to the pan. Quarried rock samples were crushed and screened from $\frac{3}{4}$ in. to No. 4 and combined with a local natural sand for the mixes. The sand content was 45 per cent by volume in all mixes and the aggregate gradings were as follows:

SAND

Passing No. 4, retained on No. 8 sieve	15 per cent
Passing No. 8, retained on No. 16 sieve	15 per cent
Passing No. 16, retained on No. 30 sieve	25 per cent
Passing No. 30, retained on No. 50 sieve	24 per cent
Passing No. 50, retained on No. 100 sieve	16 per cent
Passing No. 100 sieve	5 per cent
Fineness modulus	2.74

GRAVEL

Passing $\frac{3}{4}$ retained on $\frac{3}{8}$ in. sieve	60 per cent
Passing $\frac{3}{8}$ in. retained on No. 4 sieve	40 per cent

The concrete mix design was based on 0.51 water-cement ratio, 3-in. slump, and approximately 4 per cent air. A 5 per cent solution of Vinsol resin was used as the air-entraining agent.

The cement used in the concrete was blended in the Bureau of Reclamation laboratory. Two different blends, each blended from 10 different Type II low-alkali cements, were used in the concrete mixes included in this study. The physical and chemical properties of these blends are as follows:

	Cement No. 8487	Cement No. 9458
Specific gravity	3.18	3.15
Compressive strength (28 days), psi	3950	4420
Specific surface, Wagner method, sq cm per g	1970	1963
Na_2O, per cent	0.16	0.16
K_2O, per cent	0.44	0.46
C_3S, per cent	41.45	40.89
C_2S, per cent	31.24	32.90

Cement No. 8487, in use prior to September 1949, was used in approximately 79 per cent of the mixes, and cement No. 9458 has been used since that date.

Each batch contained 44 lb of aggregate. The mixing time in a $\frac{3}{4}$-cu-ft-capacity Lancaster pan-type mixer was $\frac{1}{2}$ min dry and 3 min after the water was added. The slump, air content, and unit weight were obtained as soon as the mixing was completed. Four 3 by 6-in. concrete cylinders were cast from each batch. Two of the specimens were cast with stainless-steel inserts in the ends for length-change measurements; however, these measurements were not used in this correlation. The remaining two specimens were for compressive strength tests. All specimens were cured 28 days in the fog room. After the 28-day curing period, two specimens were tested for compressive strength, and the remaining two specimens were immediately subjected to the freezing-and-thawing test while completely immersed in water. These specimens were placed end-to-end in close-fitting rubber containers, and the containers were filled with water and lowered into a cabinet containing calcium chloride brine. First, cold brine was circulated around the containers for $1\frac{1}{2}$ hr and the interior of the concrete reached 10 F. Then warm brine was circulated around the containers for an equal time and the interior of the concrete reached 70 F. The freezing-and-thawing apparatus was fully automatic and the test proceeded day

TABLE I.—TEST DATA.

Water-cement ratio 0.51 ± 0.01. Air content 3 to 5 per cent.

Mix	Predominant Rock Types in Coarse Aggregate	Loss of Coarse Aggregate After 5 Cycles of Sodium Sulfate, per cent	Number Cycles of Freezing and Thawing for 25 per cent Weight Loss	Compressive Strength, 3 by 6-in. Cylinder, psi	Cement Content, lb per cu yd
M-115	Natural gravels-limestones, dolomitic limestones, quartzites, quartzose sandstones, and chalcedonic cherts	6.8	900	5060	580
M-153A	Natural gravels-quartzites, sandstones, argillites, limestones	0.5	1280	5230	551
M-159	Crushed chalcedonic sandstone	1.0	1230	5370	608
M-189	Natural gravels-quartzites, granites, limestone metasandstones	1.9	800	4120	584
M-208	Predominantly crushed gravels-monzonites, granodiorites, and gneisses	8.2	900	4920	608
M-209	Same as M-208	2.2	1010	5660	614
M-210	Same as M-208	5.0	480	5470	619
M-211	Same as M-208	15.3	470	4840	614
M-215	Crushed biotite granite, moderately weathered	4.0	810	3860	591
M-221	Natural gravel-granites and gneisses	5.1	410	4270	481
M-236	Natural gravels-granites, quartz, and sandstones	6.2	660	No cylinders made	502
M-239	Crushed andesite porphyry	1.4	720	5840	629
M-241	Crushed argillaceous limestone	6.6	960	4720	596
M-251	Crushed basalt	25.0	770	4950	623
M-253	Natural gravels-andesite porphyry, andesite, and basalts	15.0	420	2860	583
M-254	Crushed chalcedonic sandstone	0.7	620	5430	653
M-258	Natural gravels-sandstones and limestones, quartzites	23.6	440	4010	624
M-262	Natural gravels-quartzites, sandstones, granodiorites, granites	16.7	770	3950	581
M-263	Natural gravels-monzonites, basalts, granodiorites, and metasiltstones	5.3	600	3920	583
M-267	Crushed dolomitic limestone	1.0	900	4040	562
M-268	Crushed basalt	3.0	1290	5670	635
M-275	Natural gravels-quartzose sandstones, 5 to 30 per cent coated with calcium carbonate	7.2	450	4750	570
M-283	Crushed granite breccia, highly fractured	22.6	760	5640	647
M-286	Natural gravels-basalts and quartzites	4.6	1290	4110	554
M-296	Natural gravels-basalts	1.0	1140	4540	589
M-298	Crushed Plattsmouth limestone	16.4	780	5400	630
M-304	Natural gravels-granites and gneisses	9.6	910	4570	550
M-306	Natural gravel-granites, quartzites, and sandstones	4.0	510	4330	559
M-319	Natural gravels-basalts and calcareous caliche	31.2	850	3580	530
M-335	Natural gravels-granites, andesite porphyry, siltstones, sandstones, and diorites	16.3	500	3610	568
M-341	Partially crushed gravels-granites, monzonites, gneisses, metasandstones, quartz diorites	4.6	750	4660	590
Clear creek	Partially crushed gravels-granites and gneisses	6.3	800	4630	533
M-347	Natural gravel-limestones, dolomitic limestones and sandstones	2.4	640	5240	584
M-397	Natural gravel-quartzite, chalcedonic sandstones, chalcedonic chert and siltstone	7.8	900	4570	596
M-423	Crushed sandstone	31.6	980	3900	631
M-427	Natural gravels-granites, gneisses, limestones, dolomites, sandstones, and quartzites	9.9	740	3900	601
M-436	Natural gravels-granites, pegmatites, vein-quartz and quartzites	16.8	530	3300	500
M-449	Natural gravels-granites, pegmatites, quartzites, and sandstones	7.2	970	3240	494
M-450	Same as M-449	4.0	930	3350	478
M-457	Natural gravels-granites, gneisses, and pegmatites	15.4	960	3090	544
M-462	Crushed quartz monzonite	11.6	520	4550	604
M-463	Crushed argillite	1.6	1260	4430	605
M-468	Natural gravels-basalts partially coated with calcium carbonate	6.2	740	5110	588
M-486	Natural gravels-granites and gneisses	13.8	530	3640	594
M-487	Same as M-486	10.4	500	3850	590

TABLE I.—*Continued*

Water-cement ratio 0.51 ± 0.01. Air content 3 to 5 per cent.

Mix	Predominant Rock Types in Coarse Aggregate	Loss of Coarse Aggregate After 5 Cycles of Sodium Sulfate, per cent	Number Cycles of Freezing and Thawing for 25-per cent Weight Loss	Compressive Strength, 3 by 6-in. Cylinder, psi	Cement Content, lb per cu yd
M-489	Same as M-486	7.8	660	4190	598
M-492	Same as M-486	13.6	560	3920	587
M-493	Same as M-486	16.4	600	3580	602
M-494	Crushed Plattsmouth limestone	44.1	240	3680	612
M-495	Crushed Kerford limestone	20.6	670	4340	619
M-496	Crushed Plattsmouth limestone	49.4	160	4200	607
M-499	Crushed quartzose sandstone	4.0	600	4770	610
M-500	Crushed quartzose sandstone	4.2	490	4720	655
M-504	Crushed limestone	8.8	700	5100	625
M-552	Natural gravels-limestones, andesites and latites	9.8	800	3650	550
M-560	Crushed dolomite cemented sandstone	3.8	940	5130	605
M-563	Crushed quartzose sandstone	2.6	690	4310	596
M-588	Crushed limestone	4.6	830	4800	572
M-589	Crushed gravels consisting of limestones, schists, and amphibolites	17.4	520	4260	569
M-613	Natural gravels-granites, pegmatites, quartz, quartzites, and gneisses	11.6	790	4110	569
M-648	Natural gravels-granites, pegmatites, gneisses, quartzites, and crystalline quartz	8.0	570	4230	572
M-681	Natural gravels-granites and argillaceous sandstone	23.9	790	3790	744
M-688	Same as M-681	23.8	720	3010	576
M-699	Partially crushed gravels-quartzites, metasandstones, granites, aplites, and monzonites	11.8	1300	4770	666
M-705	Natural gravels-cherts, quartzites, sandstones, limestones, and glassy volcanic rocks	1.8	700	3510	594
M-773	Natural gravels-quartzites, metasandstones, granites, aplites, granophyres, and rhyolites	4.4	1070	4030	608
M-779	Natural gravels-andesite and rhyolite porphyry, andesites, diorite, and quartzite	1.4	810	3720	558
M-789	Natural gravels-granites, syenites, monzonites, diorites, andesites, and quartzites	2.4	620	3830	554
M-834	Crushed limestone	18.2	480	4700	569
7314	Crushed limestone	38.6	120	2040	525

and night. Fifty complete cycles were obtained each week, allowing ample time for examining and measuring the specimens.

The specimens were measured and weighed weekly at the end of each 50 cycles until they had lost 25 per cent of their original weight, which is considered failure.

Statistical Methods:

The linear correlation coefficient, commonly designated r, measures the degree in which two variates tend to be associated in value. When all observations of two variables fall on a straight line, r equals $+1$ or -1; when r equals 0, there is no linear relationship between the variables.

Small correlation coefficients may be significant if they are estimates from a large number of tests. On the other hand, the value r equals 0.8 may frequently be encountered in samples of five pairs drawn from a noncorrelated population.

The correlation coefficient is considered "significant" when the value is higher than would occur by chance, based on statistical probability. Generally, the term "significant," as applied to the correlation coefficient, indicates that the probability of chance occurrence would be less than 5 in 100. The term "highly significant" indicates that the probability of chance occurrence would be 1 or less in 100.

When the correlation coefficient is known, the equation of the "line of best fit" (*regression equation*) and the error in predicting one factor from the other (*standard error of estimate*) can be determined.

The large amount of test data available did not lend itself readily to statistical study because of the many variables in the materials and the concrete. The aggregate samples which were submitted from many locations were small, and in many cases standard conditions of mix design could not be met with only one batch of concrete.

Some of the coarse aggregates used in these tests were manufactured from quarry rock; others consisted of comparatively well-rounded river-worn material. The gravels varied from very soft, highly porous, and absorptive to hard and dense. The cement content of the various concretes varied from 475 to 744 lb per cu yd in order to maintain a uniform water-cement ratio and slump.

All of the sands used in the concretes were natural river-worn material. They had sulfate losses ranging from 0.8 to 16.8 per cent.

In order to reduce the variables, the following conditions were established for comparing the data:

1. Water-cement ratio of concrete 0.51 ± 0.01 by weight.
2. Air content of concrete 3 to 5 per cent.
3. Two to four in. of slump.

No limitations were placed on the sulfate soundness of the sands used in the concrete mixes.

As a result of this study, the following conclusions were established:

1. Statistical analysis indicates a correlation between the freezing-and-thawing durability of air-entrained concrete and soundness of the coarse aggregate as measured by the sodium sulfate test. The wide scatter obtained, however, shows that the durability is influenced by other factors that are not measured by the soundness test.

2. In general, durable concrete was obtained with aggregates that showed as much as 32 per cent loss in the sodium sulfate soundness test with concretes containing 4 per cent entrained air and with a water-cement ratio of 0.51 by weight.

3. The cement content of air-entrained concretes of equal water-cement ratios did not significantly influence their resistance to freezing-and-thawing action.

4. The compressive strength of air-entrained concretes having equal water-cement ratios was influenced by the cement content of the concrete and the soundness of the coarse aggregate as measured by the sodium sulfate soundness test.

DISCUSSION

Mr. K. B. Woods.[1]—Was any attempt made by the authors to study the void characteristics of the aggregate?

Mr. W. H. Price (*presented paper for author*).—The answer to your question is no, but I will ask Mr. Mielenz, who is in the audience somewhere, if he has studied any of these aggregates for void content.

Mr. R. C. Mielenz.[2]—All of these aggregates have been analyzed pretrographically. Indeed all aggregates to be used in construction by the Bureau of Reclamation are subjected to thorough petrographic analysis. Our standardized testing of aggregates includes both petrographic analysis and physical properties tests. Freezing and thawing tests are performed on concrete containing the aggregate. The decision upon suitability of the aggregate for use is based upon data from all of these procedures. Divergent indications occasionally are obtained from the sodium sulfate soundness test in contrast to the freezing-and-thawing test of concrete. The discrepancy commonly relates to the size and continuity of voids, as Mr. Woods implied by his question.

The problem of freezing-and-thawing durability of both concrete and rock has been of considerable concern to us for many years. In particular, a paper by Mr. R. F. Blanks published recently[3] describes work in which void size and continuity are correlated with freezing-and-thawing resistance of both rock and of concrete. The data demonstrate that very small voids, particularly those less than 5 μ in diameter, are very deleterious to freezing-and-thawing durability. Conversely, if the voids are larger than 5 μ, resistance to freezing and thawing normally is not impaired even if porosity is high.

Mr. Fred S. Reagel[4] (*by letter*).—It is highly gratifying to see an extensive use of statistical methods such as the authors of this paper have undertaken. It is the writer's belief that in the concrete field more use should be made of mathematical tools, especially the science of statistics. However, in the greater utilization of statistics care should be taken not to overlook the limitations of its use.

The following comments are offered on the use of the statistical terms "highly significant" and "significant" in the authors' presentation. The use of the phrase highly significant trend in the second and third paragraphs on page 1162 is misleading. If used with its pure statistical connotation, it is incorrectly applied to describe the trend which the data present and if used with its more common meaning, it still describes incorrectly the trend of the data. In the tabulations the correlation coefficients of −0.390 and 0.450 obtained indicate little direct linear relationship between the variables investigated. The strength or degree of the relationship or correlation is a function of the numerical value of the correlation coefficient, which varies from −1 (perfect negative correlation) to 0 (no correlation) to +1 (perfect positive correlation). For most practical purposes a correlation coefficient of 0.8 or greater should be obtained before estimates of the dependent variable from the independent variable can be made with a high degree of accuracy.

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[1] Associate Director, Joint Highway Research Project and Professor of Highway Engineering, Purdue University, Lafayette, Ind.

[2] Head, Petrographic Lab., U. S. Bureau of Reclamation, Denver, Colo.

[3] *Transactions*, American Society of Civil Engineers, Vol. 115, p. 403 (1950).

[4] Chemical Engineer, Marquette Cement Manufacturing Co., Chicago, Ill.

When a correlation coefficient is stated to be highly significant or significant, it indicates that, if the attributes tested were uncorrelated (zero correlation) in the universe sampled, the probability is very small that a random sample would be drawn which would exhibit a correlation coefficient of the magnitude obtained. There follows from this the implication that there is a rather large probability of other random samples from the same universe yielding correlation coefficients, the magnitude of which would result in their being classed as significant.

In view of the foregoing, it is not considered very likely (with sample populations as large as those indicated in this paper) that correlation coefficients as large as those in Figs. 1, 2, and 3 would be obtained due to chance alone. Therefore, the variables in Figs. 1, 2, and 3 are considered to be related. However, the strength or degree of relationship as indicated by the numerical values of the correlation coefficients (all below 0.500 even though they are highly significant) is very weak as described by the regression equations. This lack of strong linear correlation indicates that some other variable or variables that have not been considered in the analyses are probably affecting the relationship. It is the writer's impression that this lack of degree of correlation indicated by the authors' data is not stressed enough in their presentation.

The authors' analyses indicate a probability that other factors are influencing the relationship of the variables investigated. Perhaps further study of various subgroups of the data, the subgrouping being carried out in such a manner that the effect of the interfering factor or factors is eliminated, might show better relationship of the variables within each subgroup. The technique of multiple correlation might also be used to establish a better relationship if one exists.

MESSRS. C. A. VOLLICK AND E. I. SKILLMAN (*authors*).—It is recognized by the authors that there are several factors, including small variations in air content and water cement ratio, which are not taken into account in this correlation. The largest variable found in the mix data was the cement content. Correlation between cement content and freezing-and-thawing durability did not prove significant, and the variation in cement content is considered to have less effect on freezing-and-thawing resistance of concrete than the quality of the coarse aggregate.

The concrete freezing-and-thawing test is now performed on all aggregates tested in the laboratory, and we have more confidence in the results of concrete tests than in the majority of the usual acceptance tests.

EXPERIMENTAL EXPOSURE OF CONCRETE TO NATURAL WEATHERING IN MARINE LOCATIONS*

By Herbert K. Cook[1]

Synopsis

More than 2500 concrete test specimens have been exposed to natural weathering at four exposure stations during the past 16 years by the Concrete Research Division of the Waterways Experiment Station and its predecessor concrete laboratories. The principal stations are located in Maine and Florida on the Atlantic Coast and are so situated that the test specimens are alternately immersed in sea water and exposed to air with the rise and fall of the tides.

The principal findings of this program, to date, have been that:

(*a*) At the Florida station, well-made concrete containing good-quality materials is not seriously affected by the exposure unless the portland cement used contains well in excess of the maximum calculated tricalcium aluminate content permitted by specifications for Type II portland cement.

(*b*) At the Maine exposure station, where severe freezing and thawing occurs, well-made concrete containing good-quality materials will not ordinarily withstand the exposure for more than one winter unless the concrete contains proper amounts of entrained air. When poor materials are used, proper air entrainment cannot be expected to insure durability. Variations in methods of curing apparently have little effect on durability but the use of absorptive form linings appears to improve the durability of formed surfaces. Various non-air-entraining admixtures and materials blended with the cements neither materially benefits the durability of non-air-entrained concrete nor materially harms the durability of air-entrained concrete. Tentative correlations indicate that the natural weathering at the station in Maine is not materially less severe than the laboratory procedure for testing specimens by rapid freezing and thawing in water.

Between 1935 and 1952 the Waterways Experiment Station of the Corps of Engineers, U. S. Army, through its Concrete Research Division and its predecessor concrete laboratories, has exposed 2556 concrete specimens to natural weathering. The principal exposure station, and the only one at which specimens have been continuously exposed since 1935, is at Treat Island (Eastport), Me. A second exposure station, which has been in use since 1940, is at St. Augustine, Fla. Other exposure stations, not now in service, have been maintained at Buzzards Bay, Mass. and at West Point and Mount Vernon, N. Y. At all but the two stations in New York, the specimens were subjected to alternate exposure to air and immersion in sea water as governed by tidal action. The geographical location of the

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* Presented at the Fifty-fifth Annual Meeting of the Society June 23–27, 1952.

[1] Chief, Concrete Research Division, Waterways Experiment Station, Corps of Engineers, U. S. Army, Jackson, Miss.

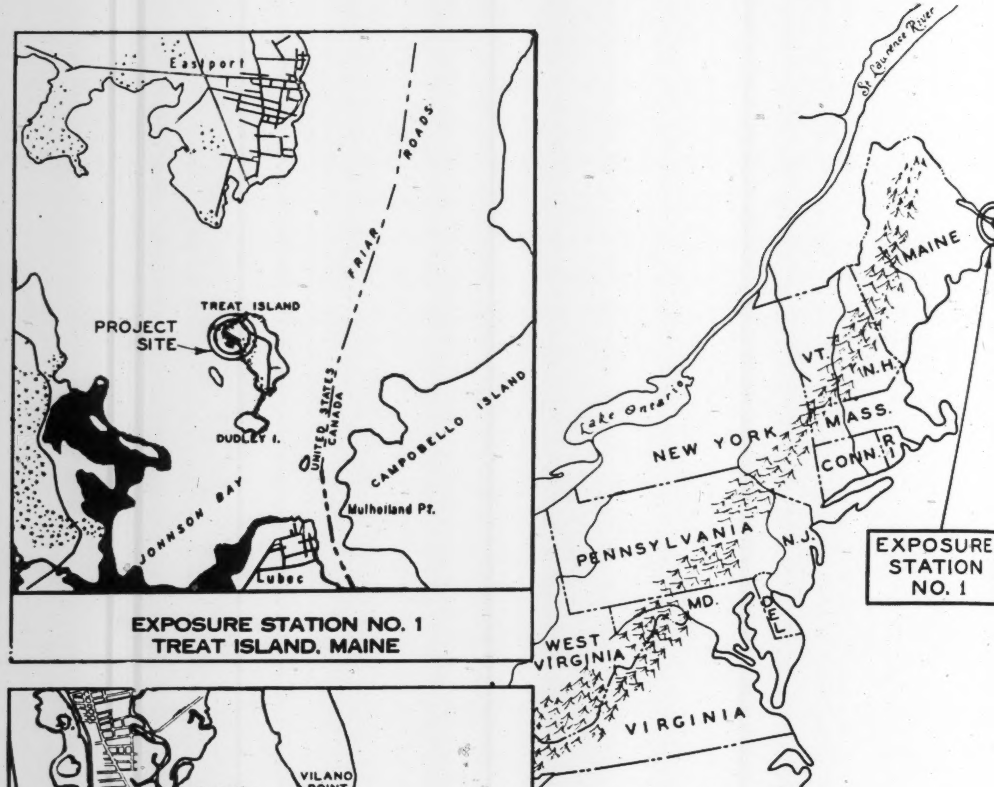
Eastport
FRIAR ROADS
TREAT ISLAND
PROJECT SITE
DUDLEY I.
UNITED STATES
CANADA
CAMPOBELLO ISLAND
JOHNSON BAY
Mulholland Pt.
Lubec
EXPOSURE STATION NO. 1
TREAT ISLAND, MAINE
St Augustine
VILANO POINT
ST AUGUSTINE INLET
Anastasia
MATANZAS RIVER
SALT RUN
BIRD ISLAND
PROJECT SITE
ANASTASIA ISLAND
EXPOSURE STATION NO. 2
ST. AUGUSTINE, FLORIDA
St Lawrence River
Lake Ontario
MAINE
VT.
N.H.
MASS.
NEW YORK
CONN.
R.I.
PENNSYLVANIA
N.J.
MD.
DEL.
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
FLORIDA
EXPOSURE STATION NO. 1
EXPOSURE STATION NO. 2

FIG. 1.—Location and Vicinity Maps of Exposure Stations Nos. 1 and 2.

two stations now in use are shown in Fig. 1. Detailed results of the various programs of investigation are given in laboratory reports (**1, 2, 3, 4, 5, 6, 7, 8, 9**).[2]

The purpose of this paper is to review the results of the exposure of concrete specimens from the several essentially unrelated investigations and to summarize the major information revealed thereby as related to the durability of concrete.

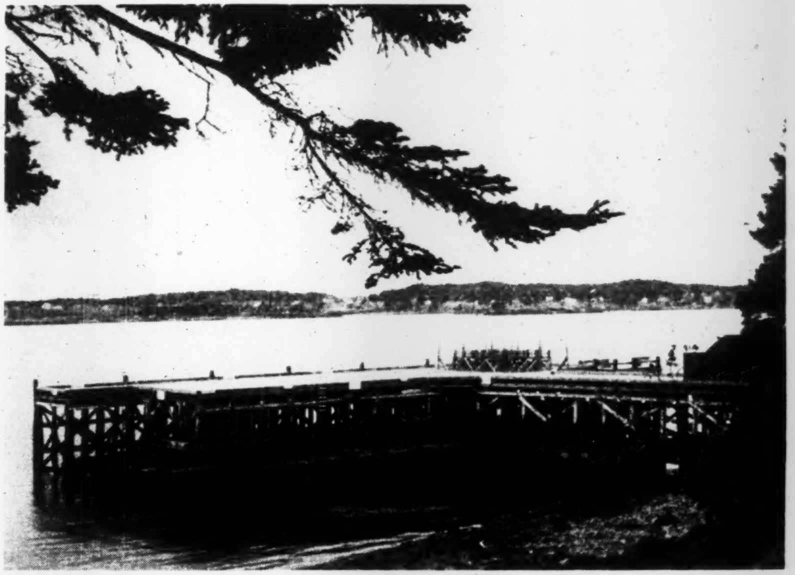

FIG. 2.—Exposure Station at Treat Island, Me.

DESCRIPTION OF EXPOSURE STATIONS

Treat Island Exposure Station:

The exposure station at Treat Island, Me. is by far the largest and most important of the stations that have been used. The exposure rack is located at mean or half-tide elevation on a Government wharf at Treat Island, situated in Cobscook Bay at the mouth of the Bay of Fundy about midway between Eastport and Lubec, Me. Figure 2 shows a general view of the wharf, exposure rack, and specimens. The normal range in tide is 18 ft with a maximum of 26 ft and a minimum of 13 ft. The volume of tidal water is such that its temperature is remarkably uniform throughout the year; varying from a low of 34 F in April to a high of 40 F in early September. During the months of December through March the air temperature averages about 14 F with a normal low of −10 F and a normal high of 36 F.

The combination of air and water temperatures during the winter months is such that the specimens are thawed in water to a temperature of about 37 F when covered at high tide and are frozen in air to a temperature of between −10 and 28 F when out of the water at low tide. The change from the frozen to the thawed condition is very rapid, thus increasing the severity of the exposure.

The principal weathering influences

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1180.

to which the specimens are subjected are freezing and thawing in the winter and wetting and drying in the summer. The influence of the sulfates in the sea water on the specimens is apparently insignificant probably because the uniformly low temperature of the water is not conducive to chemical action. Further evidence of the lack of chemical action as a factor in the failure of specimens at Treat Island is the complete absence of any indication of deterioration of many comparable specimens installed in warm sea water at St. Augustine, Fla.

The original installation of specimens on the Treat Island rack consisted of 5 by 5 by 60-in. columns made in connection with concrete studies for the proposed Passamoquoddy Tidal Power Project. The specimens were originally installed in a vertical position. During the summer of 1940 an entirely new rack was constructed providing for the installation of the specimens in a horizontal position. Since 1940 all specimens at all stations have been installed horizontally.

St. Augustine Exposure Station:

The effects of mild marine weathering are evaluated at Salt Run, off Anastasia Island, near St. Augustine, Fla. The principle agent of attack at this installation is warm sea-water. The mean water temperature is about 70 F. The average tide range is 4.5 ft, with a maximum of 5.3 ft and a minimum of 3.7 ft. Figure 3 shows the general appearance of the rack and specimens. This station affords information on the effects of sea water on concrete specimens, apart from the effects of freezing and thawing. Companion specimens to those exposed at Treat Island in connection with a major investigation of portland cements have been exposed here since 1940. The piling shown to the right in Fig. 3 are experimental piling installed by the Portland Cement Assn in connection with its long-time studies of cement (9).

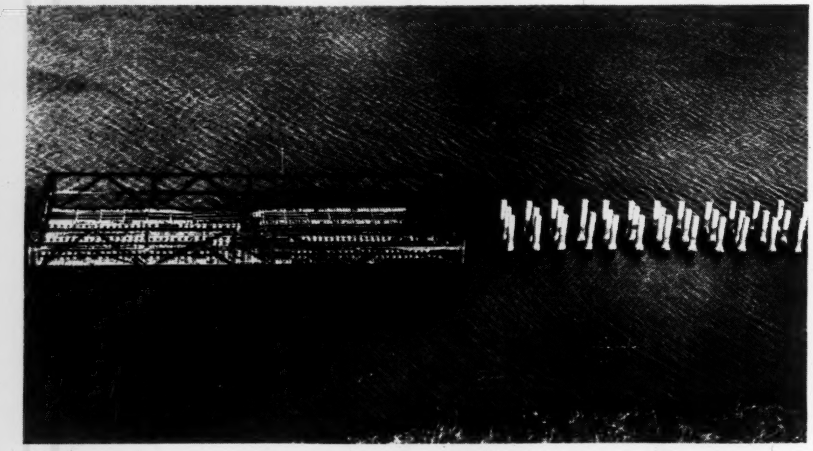

FIG. 3.—Exposure Station at St. Augustine, Fla.

Buzzards Bay Exposure Station:

The exposure station at Buzzards Bay was operated from 1938 through 1942. A total of 19 column specimens was exposed during this period in an investigation of blends of portland cement with certain admixtures. The exposure rack was located in the Cape Cod Canal near the shore opposite the Sandwich Coast Guard Station. The average tidal fluctuation is 9 ft. The Portland Cement Assn has experimental piling exposed here also for their long-time cement studies. Because of the presence of floating ice in the Cape Cod Canal during a considerable portion of the winter season and because of the fact that the water temperature drops as low as 29 F during the late winter, this station has been abandoned for installation of concrete specimens in favor of Treat Island.

New York State Exposure:

The moderate-weathering exposure installation, not involving immersion in water, used in connection with two investigations was located out-of-doors adjacent to the Central Concrete Laboratory, at the U. S. Military Academy, West Point, N. Y., between 1940 and 1942 and in Mount Vernon, N. Y., from 1942 to 1946. Companion specimens subjected to "no-weathering" were located inside the laboratory buildings at the respective locations during the respective periods.

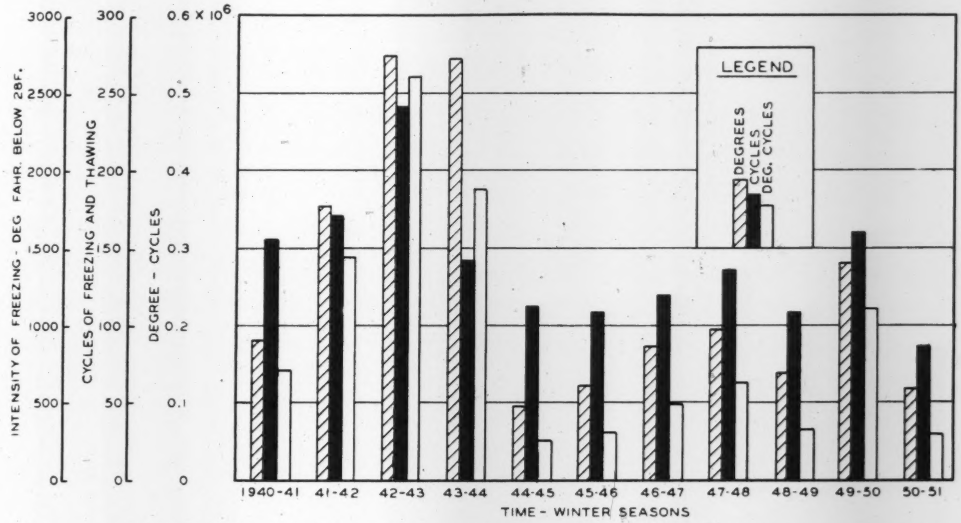

FIG. 4.—Annual Variation in Exposure of Concrete Specimens Subjected to Freezing and Thawing at Treat Island, Me.

Number of Specimens Installed at Exposure Stations:

Specimens have been installed at the various exposure stations in the years and numbers shown below:

STATION	YEAR	NUMBER INSTALLED	CUMULATIVE TOTAL
Treat Island	1936	43	43
Buzzards Bay	1938	19	62
Treat Island	1940	271	333
St. Augustine	1940	152	485
New York (outdoors)	1940	156	641
New York (indoors)	1940	52	693
Treat Island	1941	210	903
New York (outdoors)	1941	12	915
Treat Island	1942	182	1097
Treat Island	1943	767	1864
Treat Island	1944	108	1972
Treat Island	1946	82	2054
Treat Island	1947	6	2060
Treat Island	1948	300	2360
Treat Island	1949	66	2426
Treat Island	1951	130	2556

Measurement of Exposure and Testing of Specimens:

The basic factor in the three tidal exposures is the alternation of environment around the specimens produced by rise and fall of the tide. If the air and water temperatures at Treat Island were constant at below and above the freezing point of concrete saturated with sea water, then the only unit required for measurement of exposure would be "cycles of freezing and thawing". Since this is not the case, it is necessary, in making comparisons between specimens installed at different times, to introduce a correction for variable intensity of freezing. Figure 4 shows a graph on which, for each winter since 1940–41, are plotted the number of freezing and thawing cycles, the cumulative total number of degrees below 28 F measured at the center of a 6 by 6 by 36-in. concrete prism at the lowest temperature reached in each freezing cycle, and the number of "degree-cycles", a value obtained by multiplying the total number of cycles by the number of degrees below 28 F. The 28 F temperature was chosen as the approximate freezing point of concrete saturated with sea water.

In all cases where the size and shape of the specimens permit its use, the method of evaluating the effects of the exposure is successive determinations of the fundamental flexural frequency and calculations of Young's dynamic modulus of elasticity. Values for relative dynamic modulus are expressed as percentages of the modulus at the time of installation.

PROGRAMS OF INVESTIGATION

Concrete specimens have been exposed to natural weathering for the major programs of investigation described briefly below. Results indicated "to-date" are as of the spring of 1951. Results of the 1952 spring inspections were not available in time for inclusion in this paper. The results of certain programs conducted by or for other organizations are not included herein, notably 66 beams installed in December 1941 for the Portland Cement Assn in connection with its long-time study (9); 82 reinforced concrete beams for the Reinforced Concrete Research Council; and 48 beams from a joint study by the National Sand and Gravel Assn and the Public Roads Administration. The latter two groups were installed in December 1951 and no results are yet available.

Cement Durability Program:

The largest single study was an investigation started in 1939 to develop data to permit the preparation of specifications for portland cement which would insure a greater durability in concrete exposed to severe weathering than provided by the existing specifications. At that time the use of air entrainment was essentially in the discovery stage. A total of 52 samples of cement and clinker from 47 mills distributed throughout the United States was included in the study and only six of these were "treated cements." It is interesting to note that so little was known about the effect of the "treated cements" that the air content of the concrete used in the exposure specimens was not determined and those engaged in the investigation believed that about every known test for cement and concrete had been included. Hence, the only data available on air content are based on unit weight tests and microscopic examination of the hardened concrete. The fact that, of the original column specimens exposed at Treat Island in 1940, the 32 containing the treated cements were the only ones showing no deterioration in 1942 was outstanding evidence that the "treatment", or as it later developed, air-entrainment, contributed marked durability to portland-cement concrete. In 1951, after eleven winters' exposure (1472 cycles of freezing and thawing) 19 of the specimens remain and all are in excellent condition with values for dynamic modulus of elasticity of more than 100 per cent, except for one which is 94 per cent.

After eleven years of exposure at St. Augustine, Fla. only eleven of the 152 specimens from this same series have failed and, of these, eight contain cements with calculated tricalcium aluminate contents in excess of 12 per cent.

The specimens exposed to moderate and no-weathering in New York developed no data of significance except that the cement showing poorest durability at Treat Island showed map-cracking after 5½ years of moderate weathering.

Natural Cement Program:

This investigation compared the relative durability of concrete containing blends of natural and portland cement, with similar concrete containing portland cement, both with and without entrained air. Ninety-four columns representing the various test conditions were installed at Treat Island in October 1942. The results of the program to date indicate that if the natural cements contain appreciable quantities of an air-entraining addition their blending with portland cements greatly improves the durability of concrete.

Air-Entrainment Program:

It was known from the results of the cement durability program previously described, that the use of cements containing air-entraining additions materially increased the durability of concrete. The principal purpose of the air-entrainment program was to determine whether this increase in durability was due to the air-entraining addition, as such, or was due to the entrained air. In October of 1943, 182 concrete columns were installed at Treat Island. The specimens represented five plain portland cements, five portland cements with 0.03 per cent flake Vinsol resin, five portland cements with 0.01 per cent neutralized Vinsol resin, and five portland cements with 0.02 per cent neutralized Vinsol resin. All of the Vinsol resin, both flake and neutralized, was interground with the cement at the mill. Two types of coarse aggregate were used; rounded siliceous gravel, and crushed trap rock. The fine aggregate for all concrete was natural siliceous sand. Except for the concrete containing neutralized Vinsol resin, one-half of the series was mixed under normal air pressure and one-half in a vacuum of 60 mm of mercury. The purpose of the vacuum mixing was to preserve the effect of the air-entraining agent, if such effect was a factor, but to remove the entrained air. After seven winters of exposure 142 of the 182 specimens remain in sound condition. The results indicate the superior durability of concrete containing entrained air, and of concrete mixed in air, compared with that mixed in a vacuum.

Curing Program:

In February 1943, 300 concrete specimens were prepared to study the effect of the method of curing on the durability of the concrete. The specimens (3½ by 4½ by 20 in.) were sawed from laboratory-cast slabs, at the end of the curing period. After sawing, the specimens were installed at Treat Island in 100 boxes (3 per box) in such a manner that only the finished or formed surface was exposed. The test variables were ten different liquid membrane-forming compounds, water, waterproof paper, and one integral curing material. Specimens were taken from concrete both with and without entrained air placed in thin horizontal members cast on forms simulating floors or bridge decks, thin sections placed on damp earth simulating pavements, and thin vertically cast sections simulating walls or parapets. Oiled wood forms, and two types of absorptive form lining were used in making the vertical sections. After an exposure of four and a half winters only one of the specimens had failed. In May 1947, to intensify the exposure, the specimens were removed from the insulating boxes and exposed to weathering effects on all surfaces. Failure of specimens has not progressed to the point where any conclusive results can be drawn.

Durability of Horizontal Joints in Mass Concrete:

The durability of construction joints in mass concrete as affected by the method of consolidating the upper surface of the lower lift, the method of cleaning the top of the lower lift, and the use of grout between the lifts has also been studied. Cores extracted from four projects were subjected to detailed examination in the laboratory and were exposed at Treat Island:

PROJECT	NUMBER OF CORES EXPOSED	DATE INSTALLED
John Martin Dam...	10	October 1942
Bluestone Dam.....	40	December 1943
Dale Hollow Dam...	23	December 1943
Norfolk Dam.......	4	March 1943

While the interpretation of the results was complicated in some cases by difficulty in locating the joint, inadequate area of joint plane, or failure of the adjacent concrete coincidental or prior to joint failure, the following general conclusions were drawn:

1. The quality of the joint is governed largely by the quality of the concrete immediately below it.

2. Adequate development of the influence of type of clean-up, use of grout, and type of surface-curing was not obtained principally because the size of the cores that could practically be taken from the structures were too small in proportion to the area of the joint surface to secure true representation.

Durability of Mass Concrete:

Several specimens of mass concrete have been exposed at Treat Island in recent years for durability testing as follows:

(*a*) Sixty-eight 6-in. diam. cores drilled from laboratory-made mass concrete (3½ and 4 bags per cu yd cement factor, coarse aggregate graded to 4 in. in size), were exposed in June, 1946. Surfaces were formed against oiled wood, and against absorptive form lining. Each core was encased, except for the formed face, in a 2-in. thickness of mortar. All of the cores are sound to-date, the surfaces formed against absorptive form-lining being generally in better condition than those formed against wood forms.

(*b*) Six 8 cu ft concrete cubes representing concrete with 2.0, 3.0, and 4.0 bags of cement per cu yd, Type II and Type IV cement, entrained air, and aggregate proposed for use in the Pine Flat Dam, were exposed in September, 1947. All of the cubes are in good condition showing no deterioration except for minor raveling of the edges and some spalling. Three 10-in. cores from concrete of similar cement factors, all containing Type IV cement and the aggregate actually being used on the Pine Fat project were exposed in the fall of 1949. In the spring of 1951 all of the cores had relative dynamic moduli of elasticity of more than 100 per cent.

(*c*) In the fall of 1949, nine 10-in. diam. cores taken from a 70-cu-yd test block of Prepakt concrete were exposed at Treat Island. All have relative E values in excess of 100 per cent.

(*d*) Thirty-six 10-in. diam. cores and ten 8-in. diameter cores representing mass concrete with vacuum-treated surfaces were installed at Treat Island in the fall of 1949. These cores also are still in excellent condition.

(*e*) Eleven 10-in. diam. cores drilled from mass concrete in the Mt. Morris Dam were installed at Treat Island in the fall of 1949. These also had relative E values in excess of 100 per cent in 1951. Exposure of all of the above specimens has not been sufficient to permit the drawing of any comparisons or particular observation except that it is interesting to note that the blocks containing only 2.0 bags of cement per cubic yard, exposed in 1947 are still in good condition.

Exposure of Specimens from Projects:

Rome Air Depot, Rome, N. Y.—In December 1941, 15 beams made from job-mixed concrete at this project were installed at Treat Island. They represented plain portland cement, natural cement blended with plain portland cement, Vinsol-resin-treated portland cement, and Vinsol-resin-treated portland cement blended with natural cement. In October 1943 three beams sawed from runway slabs containing interground Vinsol resin were installed on the rack. Except for the specimens made with plain portland cement, all of which failed during the first winter, the specimens are in excellent condition after nine winters of exposure.

Syracuse Air Depot, Syracuse, N. Y.—In October 1942, 18 beams made from regular field batches were installed on the Treat Island rack. Six of the beams contained plain portland cement, six contained Vinsol resin interground with the cement, and six contained neutralized Vinsol resin added at the mixer. The six specimens containing plain cement failed by the end of the first winter. Four of the remaining specimens were discarded in a sound condition in August 1943 to make room for additional specimens on the rack. The remaining specimens are in sound condition and are still exposed.

John Martin Dam, Caddoa, Colo.—In October 1941, 24 columns prepared from wet-screened job concrete and 42 cores from the downstream face of the dam were installed at Treat Island. The purpose of the installation was to observe the influence of method of surface preparation on the durability of concrete. The columns were cast against oiled wood forms, and against two different types of absorptive form-lining. The cores represented surfaces cast against oiled wood forms, cast against one type of absorptive form-lining, and produced by screeding. The cores were exposed in boxes and were surrounded by fine gravel, only the formed or screeded surfaces being exposed to weathering. All specimens had either failed or were discontinued after two winters. The results indicated that the surfaces cast against absorptive form-lining were of appreciably greater durability than those obtained by the use of oiled wood forms or by screeding.

Laboratory Investigations for Projects:

Passamoquoddy Tidal Power Project.—The purpose of this installation was to find a cement-aggregate combination which would give the greatest assurance of durability for the proposed concrete structures. In connection with the study 43 concrete columns were installed in 1935. After approximately 600 cycles of freezing and thawing, six of the most durable specimens were installed on the new rack in October, 1940. Three of these columns contained plain portland cement similar to the present Type II but manufactured by a mill which permitted introduction of crusher oil by leakage. The other three specimens were made with aluminous cement. After approximately 1200 cycles of freezing and thawing the three plain concrete specimens were removed due to severe deterioration. The three columns containing aluminous cement are still sound after more than 1850 cycles of freezing and thawing.

St. Lawrence Seaway.—The purpose of this investigation was to find an aggregate that would give the greatest assurance of durability in concrete for the proposed structures. Twelve columns representing twelve test conditions involving four aggregates were exposed at Treat Island in October 1941. The results of the exposure indicated the relative durabilities of the aggregates in question and indicated that neither the presence of entrained air nor the use of absorptive form-lining are sufficient to protect concrete containing definitely unsound aggregate even though the use of such precautions greatly improves the durability of concrete made with sound aggregate. The specimens were discarded in April 1946 to provide needed space on the rack.

Stewart Field Program.—This investigation studied the effect of different types of aggregates proposed for use at Stewart Field, Newburgh, N. Y. and the use of spherical specimens in studies of the durability of concrete. In October 1943, 93 concrete spheres (12 in. in diameter) were installed at Treat Island. Due presumably to the relatively stress-free condition of the spherical specimens, all appeared to be in excellent condition except for local scaling and spalling at the time they were removed from the rack in 1949. However, tapping the spheres revealed that some of them had "dead spots" probably indicating localized areas of internal deterioration. Because of the specimen shape it was not feasible to test them for dynamic modulus of elasticity.

Admixture Programs:

A series of investigations was made to determine the relative effect of several commercial admixtures on the durability of concrete. The first series of 12 columns exposed at Treat Island in March, 1942, studied the effect of a non-air-entraining admixture when used in concrete made with plain and with air-entraining portland cement. The second series (specimens made by the National Bureau of Standards) consisted of 116 columns exposed in October, 1943, represented another commercial admixture, not basically air-entraining in nature, with 13 cements. The third series, represented by 90 columns exposed in November, 1944, included specimens representing eight commercial admixtures, seven of which were air-entraining in nature, and plain cement. The general indications are that air-entraining admixtures greatly improve the durability of concrete. Non-air-entraining admixtures tested in general showed little improvement in durability over plain portland-cement concrete, but did not adversely affect the improvement in durability shown by air-entraining admixtures when used in conjunction with them.

Comparative Field and Laboratory Durability Program:

This investigation will attempt to correlate the field exposure condition at Treat Island with laboratory freezing and thawing in the standard accelerated freezing-and-thawing equipment (10).

For this program 300 specimens were installed at Treat Island in December, 1948. Half the specimens were 3½ by 4½ by 16-in. beams and half were 6 by 6 by 30-in. beams duplicating the smaller specimens. One-hundred and fifty 3½ by 4½ by 16-in. companion beams were frozen and thawed in the laboratory. Six coarse and eight fine aggregates were used.

It is felt that at least one more winter of exposure is necessary before definite trends can be developed and any positive correlation established. It may well be that no definite correlation exists and if so it also should be understood that any correlation with this particular exposure condition does not imply any correlation with any other natural weathering. However, a few general observations of indications to date may be of interest. Twenty-six aggregate combinations in the smaller beams and 35 aggregate combinations in the larger beams had relative moduli of over 90 per cent as of May, 1951, at Treat Island. The larger specimens appear to stand the exposure somewhat better than the smaller ones. Comparing the two exposures on a cycle basis, the laboratory test appears to be more severe, however, on a degree-cycle basis the Treat Island exposure appears more severe. Nine of the 48 aggregate combinations in the smaller specimens, of which six were with quartzite coarse and three with non-chert gravel coarse aggregates, showed greater deterioration at Treat Island after 355 cycles than did their companions after 300 cycles in the laboratory apparatus.

The following comparisons are based on 300 cycles of laboratory freezing and thawing and 355 cycles of freezing and thawing at Treat Island on companion specimens:

1. The combination of natural siliceous sand and quartzite had a relative E of 86 per cent in the laboratory and 36 per cent and 84 per cent at Treat Island for the smaller and larger specimens respectively.

2. The combination of natural siliceous sand and limestone coarse aggregate had a relative E of 23 per cent in the laboratory, and at Treat Island 97 per cent for the small beams and 90 per cent for the large.

3. The combination of natural siliceous sand and non-chert stream gravel developed a laboratory relative E of 49 per cent and at Treat Island 57 per cent for the small beams and 84 per cent for the large.

CONCLUSIONS

The results obtained from the exposure of more than 2500 concrete specimens to natural weathering over a 16-yr period are the basis for the following statements relative to the value of the exposure stations and the results obtained therefrom:

1. It is of real value to be able to study concrete exposed to either mild or severe weathering for longer periods than can conveniently or economically be done in the laboratory.

2. It is of distinct advantage to be able to conduct such long-time studies in a tidal environment where the exposure is more severe and consequently more happens than a simple outdoor exposure in almost any climate.

3. Sea water of low temperature in a severe climate is a useful agent for studying the durability of concrete under severe natural weathering conditions. The effect of the chemical action of sea water, under such conditions, is essentially insignificant.

4. Warm sea water is a useful agent for studying the resistance of concrete to sulfate action.

5. The entrainment of properly regulated quantities of air is the most important factor in the improvement of the durability of concrete under severe weathering conditions that has been developed by these investigations. At Treat Island well-made concrete of good quality materials will not ordinarily

withstand the exposure for more than one winter unless the concrete contains the proper amount of entrained air.

6. The use of various non-air-entraining admixtures did not appear to be of material benefit in increasing the durability of plain concrete but were not harmful in that they did not appear to decrease the durability of air-entrained concrete.

7. The use of air entrainment does not protect concrete which contains unsound aggregate.

8. The blending of natural cement with plain portland cement greatly improves the durability of concrete if by so doing the proper amount of entrained air is produced in the concrete.

9. No definite trends in the effect of curing conditions on durability have been revealed.

10. Aluminous cement produced highly durable concrete.

11. The use of absorptive form-lining improves the durability of concrete surfaces.

12. The quality of horizontal construction joints appears to be governed primarily by the quality of the concrete at the top of the lower lift.

13. The use of cement with a tricalcium aluminate content in excess of 12 per cent has resulted in concrete that is non-durable in warm sea water. The use of Type II cement with a tricalcium aluminate content less than 8 per cent appears warranted for such exposure.

14. A certain degree of correlation appears to exist between exposure at Treat Island and rapid laboratory freezing and thawing in water at least to the extent that the natural exposure is not materially less severe than the laboratory exposure. Additional exposure at Treat Island is required before the possibility of any definite conclusions can be established.

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* These are technical reports prepared and distributed within the Corps of Engineers. Loan copies are available in most cases from the Waterways Experiment Station, Vicksburg, Miss.

DISCUSSION

MR. WALTER H. PRICE.[1]—Did the author notice any significant effect of air-entrainment in regard to sea water deterioration, particularly in the southern exposure?

MR. H. K. COOK (*author*).—I believe the answer to that is no. As described in the paper we have a number of specimens at Treat Island and companion specimens made at the same time which are exposed at St. Augustine. The greater number of specimens did not contain air entrainment. A few of them did. These specimens were installed before very much was known about air entrainment and we did not determine the air content of the concrete.

The reason for my negative answer is that at Treat Island the only specimens that are still there from that particular program are those with entrained air. At St. Augustine, the only specimens which have deteriorated were specimens of three different cements, which had tricalcium aluminate content higher than 12 per cent. Since there are specimens at St. Augustine both with air and without air that are in excellent condition, we cannot say from our exposure at St. Augustine that entrained air has improved the durability of the specimens with cements that had a low C_3A content. That may be because the exposure has not been long enough, but the actual fact of the matter is that those with air and those without are still in good condition except for the high C_3A cement.

MR. NORMAN H. WITHEY.[2]—Were surface waterproofing agents, particularly of the new silicone type, included in the tests with curing compounds?

MR. COOK.—I can make it really brief and just say no, but I should add that this group of specimens was installed before these new silicones came out. There were no silicones included in the exposure group.

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[1] Chief, Engineering Laboratories Branch, Bureau of Reclamation, Denver, Colo.

[2] President, Norman Withey and Co., Inc., Madison, Wis.

PERFORMANCE OF CONCRETE SPECIMENS DURING 10 YEARS EXPOSURE TO SEVERE NATURAL WEATHERING*

By W. J. McCoy[1] and S. B. Helms[1]

Synopsis

Results of an unusual test method are presented in which small concrete beams were stored outdoors in water in shallow concrete trays. This exposure subjected the specimens to an assured minimum of 50 cycles of natural freezing and thawing each winter while in a state of saturation. Resistance to weathering was evaluated by semiannual inspections and determination of modulus of elasticity of the beams using the sonic method. In the usual case, failures were accompanied or preceded by cracking of the specimens which seriously impaired the significance of sonic tests on beams so affected. Cements were selected which represented all five ASTM types, including air-entraining types I and II, and a group of type I cements from various points of manufacture. In one test group the several cement types were studied at two fixed cement contents in concretes placed at the same consistency. Five type I cements were each used to make three sets of specimens at different slumps with cement content varied to maintain a given water-cement ratio. The progressive changes in the specimens at this water-cement ratio show a marked reduction of weathering resistance for the mixtures made at the highest slump. Concretes with entrained air showed advantages of improved performance. Illustrations show the condition of specimens after 10-yr exposure.

At the Conference on Durability of Concrete held at Washington, D. C., in May 1940, under the joint sponsorship of the Highway Research Board, the American Society for Testing Materials, and the American Concrete Institute, J. C. Pearson[2] expressed a desire to initiate a test program and develop a set of natural weathering test conditions which would be severe enough to distinguish durable concrete from nondurable combinations within a period of about 5 years. It was desired to eliminate the unnatural factor of thermal shock which is characteristic of accepted laboratory accelerated freezing-and-thawing techniques. As a result of the interest expressed at the meeting, Mr. Pearson was encouraged to start the tests described in this paper. This approach was viewed as one which would supplement the more extensive Long-Time Study of Cement Performance sponsored by the Portland Cement Assn. Mr. Roy N. Young, who was then serving as Vice Chairman of the Portland Cement Assn. Technical Problems Committee, cooperated in the formulation of our test program.

The principal objectives were:

1. To determine whether the conditions of exposure would constitute a satisfactory outdoor accelerated test when

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Director of Research and Research Engineer, respectively, Lehigh Portland Cement Co., Coplay, Pa.

[2] J. C. Pearson, General Discussion, "Symposium on Freezing-and-Thawing Tests of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 1247 (1946).

partially immersed concrete beams would be subject to severe weathering.

2. To investigate the relative resistance to weathering of the five standardized types of cement and five typical commercial type I cements.

3. To study the effect of varied cement content and consistency on the durability of concrete.

The outdoor exposure was started at the time when dynamic measurement of modulus of elasticity was achieving prominence as a favored technique in durability testing. The sonic method was regarded as the best possible means of following the eventual deterioration of the specimens. Concrete mixtures were made from Delaware River sand and $\frac{3}{4}$-in. max size gravel with 12 selected cement samples and were placed in 3 by 3 by 15-in. molds. Additional 3 by 6-in. cylinder specimens were made for tests of compressive strength and for use as companion specimens in the outdoor exposure.

To provide a severe set of exposure conditions, special concrete basins were constructed using type III cement. The two trays, shown in Figs. 1 and 2, measured $3\frac{1}{4}$ ft by 12 ft and were designed to retain a max depth of 2-in. water. The small beam specimens and companion cylinders were made in November 1941 and exposed early in December.

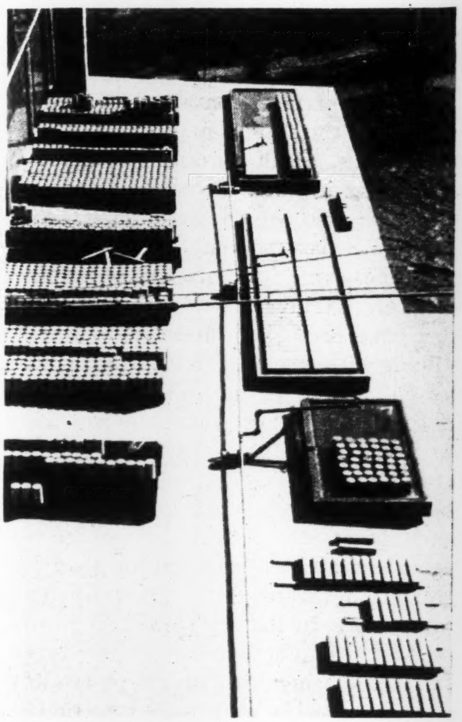

FIG. 1.—Beams and Cylinders First Stored in Basins, December 1941.

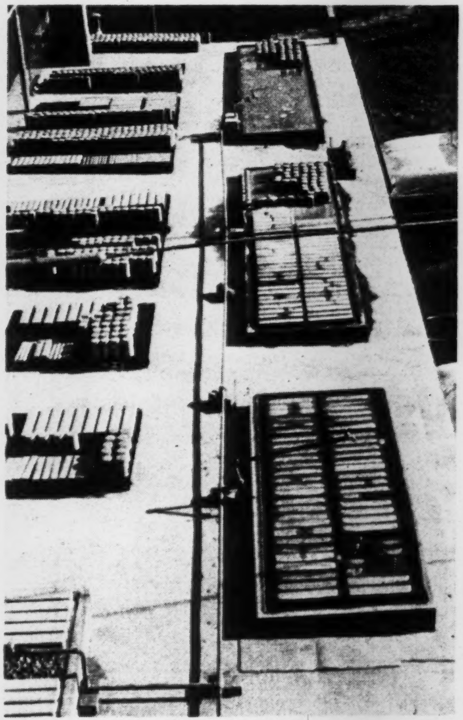

FIG. 2.—Specimens after 10 yr Exposure in Basins, December 1951.

MATERIALS AND SPECIMENS

Many of the cements used were Lehigh cements, but additional samples were obtained from other producers for inclusion in both test groups in order to complete the desired range of compositions. Complete chemical and physical test results are given for the 12 test cements in Table I except that mortar strength data are not listed. Strength data for the specific concretes under consideration are included in Table II.

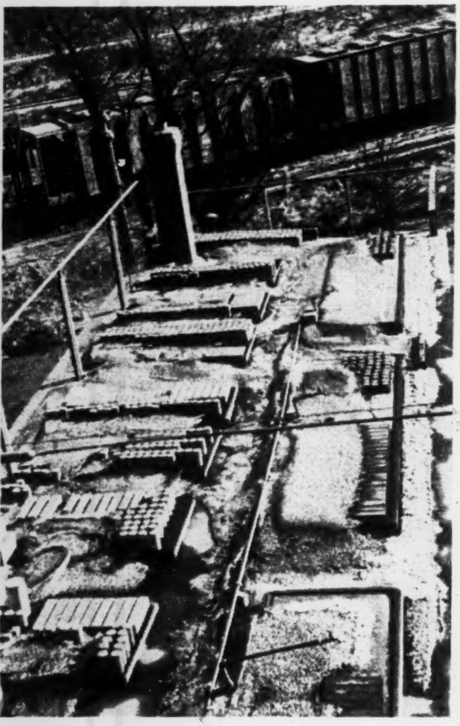

Fig. 3.—Specimens in Partially Thawed State, December 1951.

Test Group A included all five ASTM Specification types of cement, and air-entraining types I and II which were manufactured with interground Vinsol resin. These cements were used in 3-in. slump concretes with fixed cement contents of 4.5 and 6 sacks per cu yd.

Test Group B included five type I cements obtained from widely distributed points of manufacture. These samples were used in a study of the effect of consistency with cement content varied to maintain a fixed water-cement ratio which averaged 6.3 gal per sack.

The Delaware River aggregates used are described by the data which follows:

	Per cent Passing Sieve								Fineness Modulus	Saturated Surface Dry Specific Gravity	24 hr Absorption, per cent
	$\frac{3}{4}$ in.	$\frac{3}{8}$ in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100			
Sand			100	94	86	64	20	3	2.33	2.60	1.1
Gravel	100	17	0						...	2.58	1.4

All test mixtures contained 37 per cent sand with the exception of the leaner 4.5 sack mixes, which contained 40 per cent sand. Specimens were made from 0.17 cu ft batches which were repeated on successive days so that each beam in a subgroup came from a separate batch of concrete. Aggregates were weighed air dry and presoaked overnight prior to mixing with cement in a Lancaster mixer for a 3-min period. Numerous trial batches were required and care was taken to insure strict uniformity of aggregate grading in all test mixtures. Cylinder and beam molds were filled in three layers; each layer was rodded or spaded the minimum amount required for good consolidation according to the consistency of the mix. In the dry consistency mixes of Test Group B each layer was vibrated for 20 sec using a foundry type of vibrator. Test molds were sealed to prevent leakage. Cylinders for 7 and 28-day breaks were moist cured at 70 F until tested; all specimens for outdoor exposure were moist cured 7 days and thereafter stored in laboratory air for a week or more. Before making initial sonic measurements, the beams were soaked for at least 24 hr and afterward were stored in the exposure trays. Table II presents all essential information of the test mixtures, including compressive strength characteristics for the different types of cement. No air content tests were made at the time of preparing the specimens, but

TABLE I.—CHEMICAL AND PHYSICAL PROPERTIES OF CEMENTS.

Sample	Type	Chemical Constituents, per cent																Physical Characteristics[a]							
																		Fineness, per cent passing Sieve		Specific Surface, sq cm per g		Autoclave Expansion, per cent	Normal Consistency, per cent	Time of Set Gillmore Needle, hr:min	
		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss	Free CaO	Insol.	Na_2O	K_2O	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	No. 200	No. 325	Wagner	Air Permeability			Initial	Final
Test Group A (4.5 and 6.0 Sacks per yd. Concretes at 3-in. Slump)																									
No. 1	I	21.5	2.4	6.3	63.6	3.1	1.5	0.6	0.11	0.11	0.36	0.45	44.9	27.9	12.6	7.4	2.6	97.7	89.5	1815	3060	0.19	23.0	3:15	5:15
No. 6	I(AE)	21.6	2.3	6.2	63.7	3.1	1.5	0.7	0.12	0.11	0.34	0.45	45.0	28.0	12.5	7.1	2.6	97.9	89.8	1790	2880	0.17	23.0	4:00	6:15
No. 2	II	22.5	3.8	4.9	62.8	3.2	1.4	0.6	0.05	0.09	0.26	0.39	41.5	33.5	6.7	11.7	2.4	97.9	89.3	1775	2950	0.09	22.0	3:30	5:30
No. 3	III	20.4	2.1	5.4	64.7	3.3	2.2	1.5	1.45	0.12	0.28	0.26	63.0	11.0	11.0	6.5	3.8	100.0	99.7	2795	5530	0.11	29.0	2:00	3:30
No. 4	IV	26.4	2.7	3.0	63.1	1.8	1.5	0.9	0.21	0.16	0.16	0.24	27.0	55.2	3.4	8.2	2.6	97.2	94.6	1920	3270	0.01	24.0	6:30	8:20
No. 5	V	24.5	3.3	3.5	64.3	1.7	1.4	0.8	0.54	0.09	0.08	0.27	45.0	36.0	4.0	10.0	2.4	99.6	98.0	2025	3460	−0.02	24.0	6:20	8:20
No. 7	II(AE)	22.0	4.1	5.2	62.7	3.0	1.6	0.9	0.12	0.10	0.17	0.36	43.0	30.0	6.8	12.0	2.8	99.1	95.7	1930	3400	0.05	24.0	3:45	6:00
Test Group B (6¼ gal. per Sack. Concretes at No Slump, 3-in. and 6-in. Slumps)																									
No. 8	I	21.2	2.2	6.4	63.3	3.3	1.6	1.3	0.32	0.04	0.30	0.40	46.0	26.0	13.2	7.0	2.8	99.0	95.2	1860	3450	0.20	25.0	3:15	5:15
No. 9	I	21.2	2.3	6.7	62.9	3.3	1.8	0.7	0.30	0.10	0.30	0.51	41.0	30.0	13.8	7.0	3.1	96.0	86.8	1730	3350	0.44	23.5	3:50	6:40
No. 10	I	21.7	2.2	6.1	63.7	3.2	1.8	0.9	0.58	0.09	0.12	0.67	45.0	28.0	12.6	7.0	3.1	96.9	90.8	1760	3200	0.35	24.5	3:00	5:00
No. 11	I	20.2	3.5	6.5	63.5	3.0	1.7	1.0	0.66	0.03	0.27	0.45	52.0	19.0	11.3	11.0	2.9	98.0	94.8	1800	3400	0.21	24.0	2:50	4:30
No. 12	I	22.0	2.47	4.87	62.9	3.34	1.83	0.5	0.08	0.06	1.08	0.47	48.0	27.0	8.7	8.0	3.1	93.5	86.5	1860	2920	0.21	22.5	3:45	6:00

[a] Mortar compressive strengths not listed; see Table II for compressive strength of concrete in both test groups.

some computed gravimetric air contents have been appended to the table to serve as verification of the presence of entrained air. Other calculations gave satisfying evidence that none of the test cements were air entraining except cement Nos. 6 and 7.

TABLE II.—PROPERTIES OF TEST CONCRETES.

Cement	ASTM Type	Cement Content, sacks per yd	Slump, in.	Unit Wt[a] lb per cu ft	Water Cement Ratio, gal per sack	Compressive Strength, psi, Moist Cured 3 by 6 in. Cylinders	
						7 days	28 days
Test Group A (Refer to Table III)							
No. 1	I	4.5 6.0	3.6 2.7	143.7 146.7	8.7 6.0	1510 3850	2950 6090
No. 6	I(AE)	4.5 6.0	2.6 3.3	140.4[b] 142.6[b]	7.6[b] 5.7[b]	1760 3240	3280 5200
No. 2	II	4.5 6.0	3.6 3.0	144.4 147.3	8.6 6.0	1020 2450	2400 5470
No. 3	III	4.5 6.0	3.4 3.0	145.2 146.9	8.6 6.3	3170 5780	3830 6920
No. 4	IV	4.5 6.0	2.9 2.8	145.4 147.8	8.4 5.9	472 1330	1350 3240
No. 5	V	4.5 6.0	3.2 2.7	145.2 148.0	8.4 5.8	973 2640	1950 5200
No. 7	II(AE)	4.5 6.0	3.4 2.7	141.9[c] 145.0[c]	8.0[c] 5.8[c]	1250 2920	2880 5640
Test Group B (Refer to Table IV)							
No. 8	I	5.0 6.0 6.3	... 3.4 6.1	147.4 146.8 147.4	6.3 6.3 6.3	4360 3980 3950	6080 5610 6320
No. 8 (+.015 per cent Al)	I	5.1 6.0 6.4	... 3.2 5.5	146.2 145.4 144.9	6.2 6.2 6.2	3740 3930 3640	5540 5930 6080
No. 9	I	5.0 6.0 6.4	... 3.0 6.2	147.1 146.6 146.3	6.3 6.3 6.3	2720 2730 2700	4250 4300 4400
No. 10	I	5.0 6.0 6.5	... 2.9 6.7	148.0 147.1 146.9	6.2 6.2 6.2	4510 4520 3790	5820 5740 6070
No. 11	I	5.0 6.0 6.4	... 3.4 6.4	148.0 146.8 146.5	6.3 6.3 6.3	4120 4200 4010	5970 5610 6180
No. 12	I	5.0 6.0 6.4	... 3.0 5.8	146.2 145.7 145.0	6.5 6.5 6.5	3790 3680 3530	5100 5130 5320

[a] Concrete density affected by varied water requirement, different sp. gr. of cements, and different mix proportions.
[b] Air content 4.4 per cent computed for 4.5 sack mix with Cement No. 6.
[c] Air content 3.1 per cent computed for 4.5 sack mix with Cement No. 7.
No other cements found to be air entraining in study of unit weight data.

EXPOSURE TESTS

Figure 1 shows the arrangement of specimens in the exposure trays at the beginning of the tests in December 1941. A similar view in Fig. 2 after 10-yr weathering contrasts with the original and reveals the general extent of failures which took place during that time. To provide an adequate reservoir of water in each tray the original arrangement of specimens was changed after five years to the plan illustrated by the groups in the center tray of Fig. 2; specimens in the foreground had been temporarily removed from the old tray in background for measuring and photographing. These failures may be studied in detail in subsequent illustrations which are close-up views of 10-yr specimens after a cleaning treatment. During exposure the 2-in. water level was maintained by refilling the trays daily and did not drop appreciably in the winter months. In other seasons the average level of the water was lowered by evaporation, and at times, such as week-end dry spells in summer, nearly all the water would be lost by evaporation before refilling on Monday. Thus there are believed to be two principal factors in the exposure—natural freezing and thawing cycles in winter and in milder weather a moisture movement by capillarity through the concrete tending to set up stresses between the upper and lower halves of specimens. Imminent failures were usually noted to be presaged by the formation of cracks near the midpoint of the beams; these extended from the top down. There were a few exceptions where the first sign was a map cracking on the top. Almost invariably the cracks could be observed at the time a decline of the sonic modulus was detected. Inclusion of dynamic test data in their entirety would be impractical and because of the accompanying cracks would be limited in significance. If all dynamic test data were presented graphically, the charts would simply show losses concurrent with the development of cracks. Therefore the principal sonic test results have been summarized in Tables III and IV (which correspond to Test Groups A and B, respectively) and are associated with the occurrence of visible defects on the specimens. Also, for purposes of correlation there are some notes appended to Tables III and IV which briefly denote the occurrence of

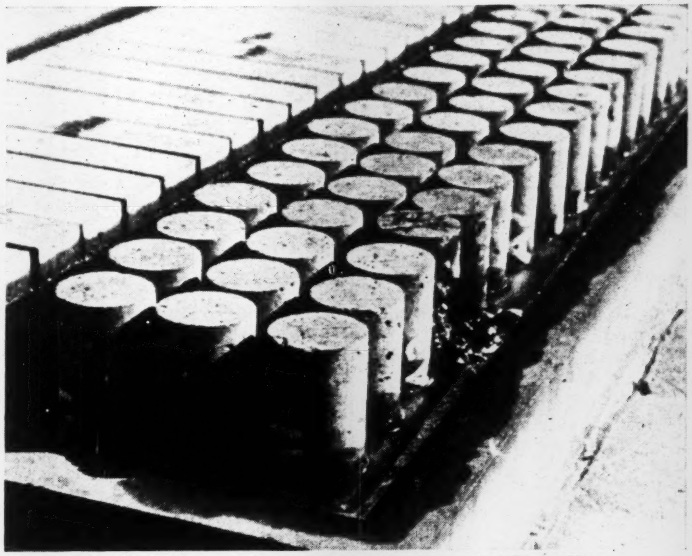

FIG. 4.—Effects of Severe Exposure After the First Winter.

Disintegration of type IV cement specimens in foreground is contrasted with other 4.5 sack concrete cylinders from Test Group A.

Dark spots on beams correspond to cracks in 5 sack concrete specimens No. 10a, No. 12a, and No. 12b. Appearance of cracks in these beams in 1942 is noted in Table IV.

TABLE III.—SUMMARIZED PERFORMANCE OF CEMENTS IN SEVERE NATURAL WEATHERING.
3 by 3 by 15-in.-Concrete Beams Stored Outdoors in Concrete Basins (water depth 2 in.).
Test Group A. Exposed in Dec. 1941.

Cement	Sample	Cement Factor, sacks per yd*	Specimen	Sonic *E*, psi				Condition Noted		Visible Defects** such as Erosion, Spalling, and Date First Noted
				Initial 1941	Prior Max		After 10 yr	After 10 yr	First Crack	
					Value	Date				
Type I	No. 1	4.5	a	3.88×10^6	5.29×10^6	’46	5.58×10^6	intact	...	Sl. Sp. sides ’45
			b	3.72	5.08	’46	...	(’50)^{c}	’47	Bad Sp. bottom ’42
			c	3.80	5.31	’47	...	(’50)^{c}	’47	none
		6.0	a	4.84	6.44	’47	6.59	intact	...	none
			b	4.87	6.37	’47	6.27	intact	...	none
			c	4.95	6.48	’47	6.67	intact	...	V. Sl. Sp. bottom ’43
Type I (AE)	No. 6	4.5	a	3.87	5.69	’44	5.23	good^{as}	’51?	V. Sl. Er. ’47
			b	3.80	5.08	’43	...	(’50)^{c}	’45	(Sonic 3.93 in ’45)
			c	3.57	5.19	’47	5.36	intact	...	none
		6.0	a	4.50	5.91	’43	6.00	excel.^{as}	’47?	(Sonic 4.80 in ’44)
			b	4.38	5.86	’43	6.09	intact	...	none
			c	4.54	5.99	’46	6.27	intact	...	none
Type II	No. 2	4.5	a	3.54	5.25	’42	2.47	poor^{bd}	’44	Sl. Er. sides ’43
			b	3.61	5.39	’43	4.58	poor^{ad}	’44	Eroded sides ’43
			c	3.86	5.61	’43	...	(’50)^{cd}	’44	End & Side Sp. ’42
		6.0	a	4.55	6.53	’47	5.89	fair^{as}	’50?	V. Sl. Erosion ’47
			b	4.60	6.54	’47	...	(’51)^{c}	’50	Practically none
			c	4.63	6.54	’47	...	(’51)^{c}	’50	Practically none
Type II (AE)	No. 7	4.5	a	3.76	5.49	’47	5.65	intact	...	none
			b	3.70	5.57	’47	5.71	intact	...	V. sl. Erosion ’47
			c	3.70	5.36	’47	5.43	intact	...	none
		6.0	a	4.59	6.31	’46	6.41	intact	...	none
			b	4.62	6.21	’47	5.82 av.	good^{as}	’50	none
			c	4.68	6.36	’46	6.51	intact	...	none
Type III	No. 3	4.5	a	4.21	5.17	’47	5.21	intact	...	Sl. Scaling top ’47
			b	4.62	5.51	’47	5.81	intact	...	none
			c	4.44	5.20	’42	...	(’51)^{c}	’44	Top Scaled ’47, Disintegrated ’50
		6.0	a	5.10	6.25	’46	...	(’51)^{c}	’50	none until cracked
			b	5.15	6.33	’47	...	(’51)^{c}	’50	none until cracked
			c	5.13	6.23	’47	...	(’51)^{c}	’50	ncne until cracked
Type IV	No. 4	4.5	a	3.09	5.91	’42	2.04^{2yr}	(’47)^{cd}	’43	Er. ends, Sp. bottom ’42
			b	3.11	5.69	’42	2.19^{2yr}	(’50)^{cd}	’43	Er. ends, side, Sp. bot. ’42
			c	2.73	5.64	’46	5.68	intact^{d}	...	Ends sl. Eroded ’42
					(No. 4c Sonic 4.61 in ’47)					
		6.0	a	4.07	6.56	’46	5.92	(’50)^{as}	...	Sl. Er. ends ’47
			b	4.07	6.56	’46	6.83	intact	...	none
			c	4.15	6.70	’46	...	(’47)^{c}	’43?	none until Cr. thru
Type V	No. 5	4.5	a	3.78	6.15	’47	6.33	good^{d}	...	Er. sides & 1 cor. ’42
			b	3.75	6.06	’47	6.22	goods^{ds}	...	Sl. Er. sides ’47
			c	3.73	5.96	’47	6.17	goods^{ds}	...	V. Sl. Erosion ’47
		6.0	a	4.85	6.86	’46	...	(’50)^{c}	’50	none until Cr. thru
			b	5.00	6.86	’46	...	(’50)^{c}	’47	none until cracked
			c	4.79	6.79	’47	7.07	good$^{as?}$	...	none

* All concrete mixes made at 3-in. slump.

** Notes on performance of companion cylinder specimens report significant defects only:

Type I No. 1 4.5 sacks. One cylinder sl. spalled ’42, bad sp. ’43, moderate deterioration ’50.
Type II No. 2 4.5 sacks. One cylinder spalled badly ’42, advanced deterioration ’50.
Type IV No. 4 4.5 sacks. All 3 cylinders disintegrated badly first winter.
6.0 sacks. All cylinders sl. Sp. ’42 and moderate Sp. ’43, unchanged thereafter.
Type V No. 5 4.5 sacks. One disintegrated first winter, other 2 sl. Sp. ’42 which increased progressively.

Symbols and Abbreviations used in Tables III and IV:

[a] Crack Apparent.
[as] Slight crack indicated.
[b] Crack Opened.
[c] Cracked in 2 pieces.
[d] Spalled at end or bottom (ds = slightly).

Er = eroded
cor = corner
bot = bottom
Cr = cracked
Sp = spalled
Sl = slight
V = very

TABLE IV.—SUMMARIZED PERFORMANCE OF TYPE I CEMENTS IN SEVERE NATURAL WEATHERING.

3 by 3 by 15 in.-Concrete Beams Stored Outdoors in Concrete Basins (water depth 2 in.)
Test Group B. Exposed in Dec. 1941.

Sample	Cement Factor, sacks per yd	Slump of Concrete*	Specimen	Sonic *E*, psi				Condition Noted		Visible Defects** such as Erosion, Spalling, and Date First Noted
				Initial 1941	Prior Max Value	Prior Max Date	After 10 yr	After 10 yr	First Crack	
No. 8	5.0	none	a	5.27×10^6	6.40×10^6	'42	6.67×10^6	intact	...	none
			b	5.25	6.32	'42	5.04	fair[as]	'44	none except sl. cr.
			c	5.01	6.22	'42	6.30	good[as]	'44	none, crack healed
	6.0	3 in.	a	4.87	6.30	'47	6.64	intact	...	none
			b	4.89	6.10	'46	6.49	intact	...	none
			c	4.76	6.15	'46	6.49	intact	...	none
	6.3	6 in.	a	4.68	6.09	'47	6.32	intact	...	none
			b	4.70	6.06	'47	6.04	intact	...	none
			c	4.77	6.10	'46	0.21	poor	'47	Map cracking failure at top
No. 8 (Plus 0.015 per cent Aluminum Powder)	5.1	none	a	4.97	6.11	'47	6.28	intact	...	none
			b	4.81	5.46	'43	...	('50)[c]	'42[a]	Slow Sp. at locale of crack
			c	4.68	4.81	'43	...	('47)[c]	'42[b]	Slow Sp. at locale of crack
	6.0	3 in.	a	4.75	5.85	'47	6.14	intact	...	none
			b	4.59	5.71	'46	3.06	fair[b]	'51	none except crack
			c	4.56	5.68	'43	4.91	good[a]	'51	none except crack
	6.4	6 in.	a	4.33	5.67	'47	5.82	intact	...	none
			b	4.52	5.96	'47	6.11	intact	...	none
			c	4.29	5.62	'47	4.04	fair[b]	'50	none except crack
No. 9	5.0	none	a	4.93	6.47	'47	6.64	intact	...	none
			b	4.89	6.44	'46	6.67	intact	...	none
			c	4.82	6.32	'47	6.59	intact	...	none
	6.0	3 in.	a	4.67	6.30	'46	6.57	intact	...	none
			b	4.61	6.19	'45	5.04	fair[b]	'50[as]	none except crack
			c	4.55	6.03	'45	0.34	fair[b]	'47[a]	none except crack
	6.5	6 in.	a	4.59	6.06	'43	$6.20^{6\text{yr}}$	bad[c]	'50[c]	Spalled at crack '51
			b	4.65	6.04	'42	$3.71^{2\text{yr}}$	bad[c]	'43[c]	Spalled at crack '50
			c	4.56	6.01	'43	...	bad[c]	'44[c]	Decay at crack '47
No. 10	5.0	none	a	5.40	6.42	'47	...	('50)[c]	'43	Sl. Sp. at locale of crack
			b	5.10	5.40	'43	...	('50)[c]	'42	Sl. Sp. at locale of crack
			c	5.17	6.52	'47	6.64	intact	...	none
	6.0	3 in.	a	5.04	6.28	'47	6.20	excel.[as]	'51	none except sl. crack
			b	5.10	6.27	'43	0.32	fair[d]	'46	Some Sp. on bottom '51?
			c	5.21	6.49	'46	6.70	intact	...	none
	6.5	6 in.	a	4.86	6.15	'46	...	('50)[c]	'47[b]	Crow ft. Cr. at top '44
			b	4.86	6.19	'46	6.39	intact	...	none
			c	4.80	6.15	47	6.34	excel.	?	Crow ft. Cr. at top '44
No. 11	5.0	none	a	5.32	6.52	'47	6.69	intact	...	none
			b	5.15	6.39	'47	6.61	intact	...	Sl. Sp. at bot. cor.
			c	5.26	6.62	'47	6.75	intact	...	none
	6.0	3 in.	a	5.04	6.20	'46	6.35	intact	...	none
			b	5.06	6.25	'46	6.41	intact	...	none
			c	5.00	6.24	'47	6.42	intact	...	none
	6.4	6 in.	a	4.93	6.16	'47	6.35	intact	...	none
			b	4.78	6.04	'47	6.03	excel.[as]	'51	none except sl. crack
			c	4.72	5.98	'46	...	('51)[c]	'50	Sp. at locale of crack
No. 12	5.0	none	a	4.75	5.59	'43	4.69	fair[b]	'42	none except partly cracked
			b	4.80	5.44	'43	...	('50)[c]	'42	none except crack
			c	4.79	6.14	'47	6.35	intact	...	none
	6.0	3 in.	a	4.47	5.80	'47	6.04	intact	...	none
			b	4.57	5.92	'47	6.02	intact	...	none
			c	4.56	5.72	'47	0.47	fair[b]	'50	none except crack
	6.4	6 in.	a	4.47	5.80	'47	5.98	intact	...	Scaling on top '44
			b	4.39	5.74	'47	0.21	fair[b]	'50	none except crack
			c	4.45	5.86	'45	0.20	fair[b]	'50	none except crack

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* Concretes had fixed water-cement ratio for each cement, see Table II.

** Notes on Performance of Companion Cylinder Specimens report significant defects only.
Type I No. 11 6-in. Slump. One cylinder partly disintegrated '47.
Type II No. 12 6-in. Slump. One cylinder partly disintegrated '47.

significant defects on the companion cylinder specimens.

Results of Exposure

The conditions of test have not proved to be as severe as intended; it was hoped that less durable combinations would show marked signs of distress within a few years. But some early differences were found that have progressed in further weathering. After 10 yr it is possible to compare the present appearance of the specimens, as shown in Figs. 6 and 7, with earlier signs of poor resistance. A record of outdoor temperature cycles was kept for the period of the first four winters that the specimens were under test. An average minimum yearly number of 57 cycles, excluding week ends, was recorded for this particular period; thus the total average number was certainly in excess of 60 cycles for those years.

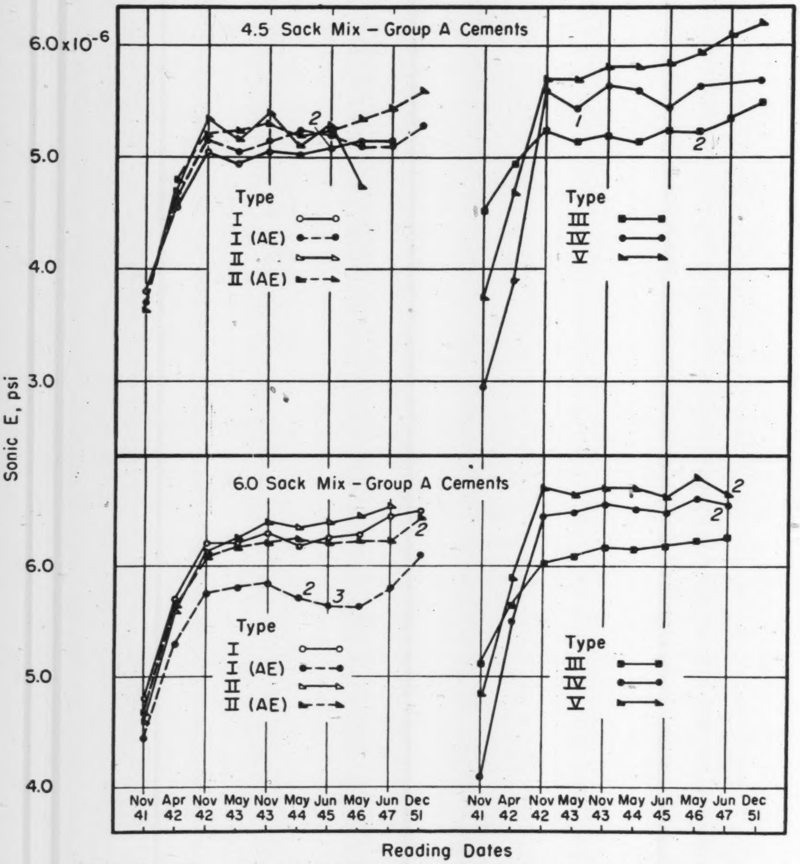

Fig. 5.—Changes on Sonic E of 3 by 3 by 15 in.-Concrete Beams.

Average 3 tests except after smaller number shown.

The sonic method[3] was used to measure the natural frequency of the 3 by 3 by 15-in. beams in a saturated condition. The measured density of specimens was used in the computation of *E* values

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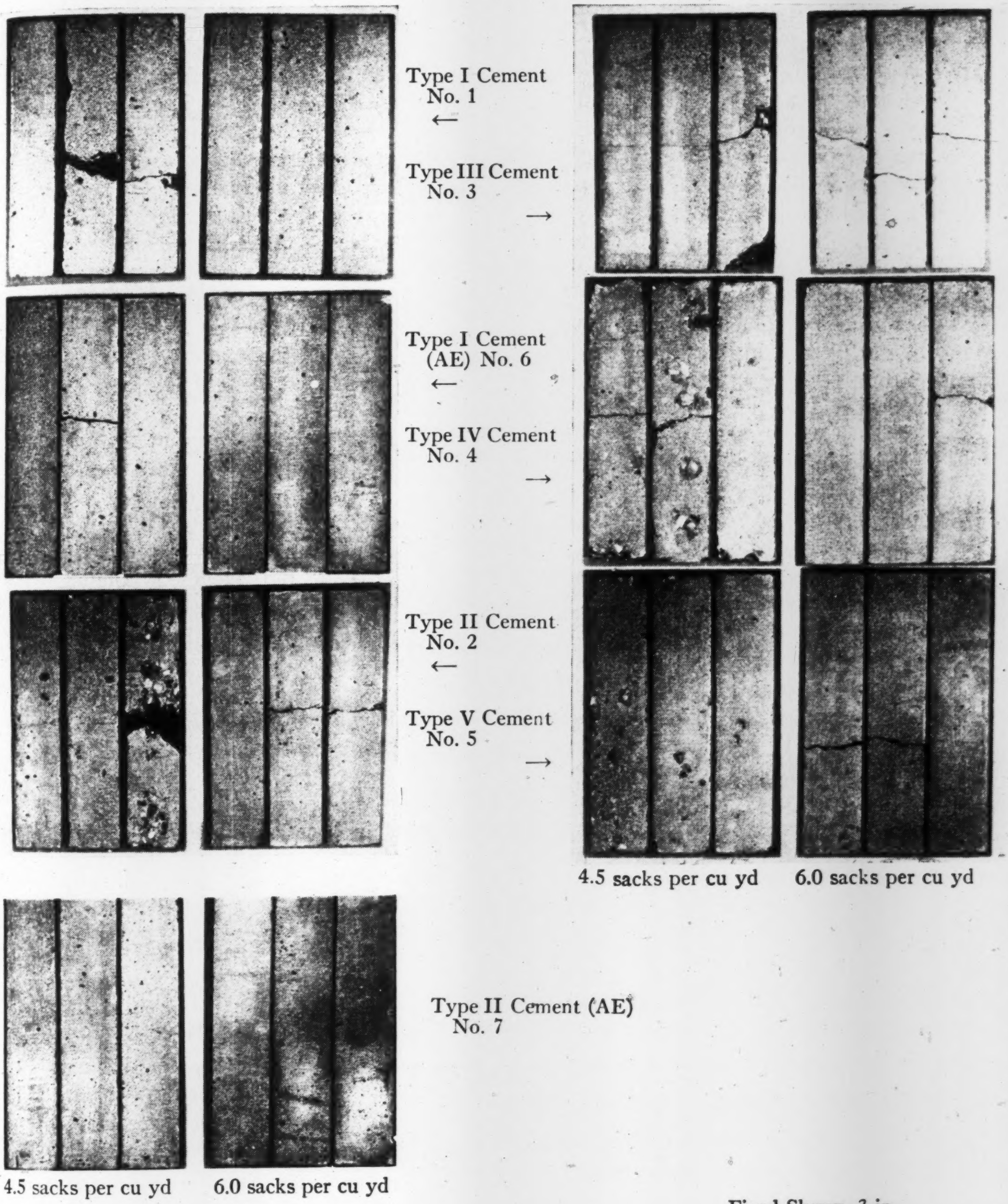
[3] F. B. Hornibrook, "Application of Sonic Method to Freezing and Thawing Studies of Concretes," ASTM Bulletin, No. 101, Dec. 1931, p. 5.


Type I Cement
No. 1
←
Type III Cement
No. 3
→
Type I Cement
(AE) No. 6
←
Type IV Cement
No. 4
→
Type II Cement
No. 2
←
Type V Cement
No. 5
→
4.5 sacks per cu yd
6.0 sacks per cu yd
Type II Cement (AE)
No. 7
4.5 sacks per cu yd
6.0 sacks per cu yd

Fixed Slump, 3 in.

Fig. 6.—Effect of Cement Content on Resistance to Severe Natural Weathering Side View of Beam Specimens after 10 yr Exposure (top edges on right).

Note—The specimens for cement No. 7 above, which represent 6 sack 3 in. slump concrete may be compared in Fig. 7 with a similar set made with non-AE type I cement No. 8 from same mill.

for modulus of elasticity according to the suggestions of Obert and Duvall.[4] After being exposed to about 50 cycles of freezing and thawing the first winter, all beams showed an increase in *E* value except 5 specimens from dry concretes in Test Group B made with type I cements and molded by vibration. Even 2 of these (cement No. 12) showed higher dynamic *E* since the cracks were too small effectively to lower the modulus due to the discontinuity.[5] The underlying reason for the early cracking of specimens from mixtures of dry consistency is conjectural since there are several possible causes.

There are 18 specimens from stiff mixtures shown in Fig. 7, and it is of interest that the majority of 8 of these beams shown cracked after 10 yr were cracked to some extent the first winter and the balance at the end of three winters. The unexpected behavior of beams which were placed by vibration may be due to the fact that these mixes were much leaner than plastic mixtures made with the same cements at fixed water-cement ratio. Table II lists cement factors of 5 sacks for dry mixes and 6.0 and 6.4 sacks, respectively, for 3- and 6-in. slumps. The cracks could also be due to inadequate consolidation or unequal distribution of cement paste caused by migration during vibration. The latter explanations are more plausible since the low cement content did not correspond to a strength deficiency.

Other significant defects on beams, noted in April, 1942, were confined to the 4.5 sack mixes with different cement types in Test Group A. Two of the three lean mix specimens made with type IV cement were spalled and slight cracks were noted; Table III reveals that the exposure cylinders of this mix were destroyed by freezing action during the first winter as shown in Fig. 4. It is very likely that the deterioration of 4.5 sack type IV cement specimens was due to slow development of strength and insufficient strength when exposed to freezing action. The illustrations for cement No. 4 in Fig. 6 show that the 4.5 sack concrete beams have not disintegrated like the cylinders but were badly cracked the following winter. This instance demonstrates the way that Table III can be used to develop the case history of any specimen illustrated in Fig. 6 or Table IV for Fig. 7.

After the second winter more defects were noticeable in the lean mix beams of Group A cements and the dry-consistency lean mixes of Group B cements. Later review of sonic test results showed that many affected specimens tended to recuperate in milder weather after experiencing a small drop in the *E* value the previous winter. This regain in *E* was even true in the case of a number of cracked beams and proved that some self-healing took place. Diagrams of changes in sonic values for beams in Test Group A have been prepared to illustrate this type of recuperative effect. Figure 5 shows these changes for specimens which were not seriously affected by cracks in the first 5 yr of exposure with a given line terminated when serious cracks developed after 1946.

DURABILITY INDICATIONS

Impending failures could not be predicted in any instance on the basis of loss of dynamic *E* and, as time elapsed, it became evident that the chief index of weathering failure was the tendency of less durable specimens to crack. M. O. Withey[6, 7] emphasized the fact that, in freezing-and-thawing tests, loss of flexural strength is a more sensitive measure of deterioration of exposed concrete than reduction of compressive strength. The cracking type of failure shown by some of our exposed beams is either a manifestation of reduction of flexural strength or the result of strong physical stresses set up in the final stages of the freezing of water in the trays or a combination of both factors. Differential shrinkage could cause cracking, but the evidence points to wintertime freezing as the prime influence. Therefore the occurrence of cracks before appearance of other signs of inferior durability may now be assigned more significance than would have been credited after the first few years of exposure. Other evidence lending support to this analysis of the failures is the relative freedom from cracking of beam specimens made with air-entraining cements which, according to the indications of Fig. 5, must have had less initial flexural strength than the plain mixes. There are other instances, such as the case of 4.5 sack type V cement mixes in Fig. 6, where a concrete known to have had relatively low strength when first exposed has shown less cracking than a stronger companion set over the 10-yr period. It would be hazardous to appraise the efficaciousness of this outdoor exposure test, and it is clear that some changes can be made to improve the method. An example of the development of the method is a test series now in progress designed to evaluate severity of exposure which compares beams stored on damp sand to some stored partially immersed. Also, future tests will not be solely dependent on dynamic *E* values but will include length change measurements.

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[4] L. Obert and W. K. Duvall, "Discussion of Dynamic Methods for Testing Concrete with Suggestions for Standardization," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1051 (1941).

[5] P. G. Kimser, "The Effect of Discontinuities on the Natural Frequency of Beams," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 897 (1944).

[6] M. O. Withey, Progress Report, Committee on Durability of Concrete, *Proceedings*, Highway Research Board, Vol. 24, p. 174 (1944).

[7] M. O. Withey, "Considerations Involved in the Making of Freezing and Thawing Tests on Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 1198 (1946).

In order to summarize the findings of this test program it would be possible to rate weathering resistance of specimens according to appearance, assign arbitrary numerical values, and thereby derive numerical averages for test groups; these would serve as quantitative indices to determine only the trends of the results because the results would be based on average values. Instead, it appeared that it would be more desirable, after 10-yr exposure, to show the condition of the individual beams so that conclusions can be reached by actual observation. Figures 6 and 7 include side views of all specimens in the two respective test groups and should be studied in connection with Tables III and IV.

Discussion of Photographs of Exposed Specimens:

Performance is typical of durability test results when specimens from replicate batches show varied endurance; beams in each set were cast on different days.

In sets of cylinders that were affected by weathering the specimen stored in the outer row in the tray was attacked most severely. (See arrangement of cylinders in Fig. 1 and similar close-up view in Fig. 4.) Although severity of exposure on 3 by 6-in. cylinders was influenced by the position in the tray, the same effect was not apparent in the case of beams. The arrangement was such that the 4.5 sack concretes of Test Group A and the 3-in. slump mixes of Test Group B were in the east rows. Positioning could have resulted in a slight advantage for specimens in the east row, but this factor is probably of minor significance.

The views in Fig. 6 for 4.5 sack beams with types I and IV cements, and 6-sack mixes with types II, III, and V, show the possibility of induced cracking due to failure of adjacent specimens.

There was little tendency for surface spalling on the sides of the specimens except in the 4.5 sack mixes with the particular samples of type II, IV, and V cements used in the study. It is entirely

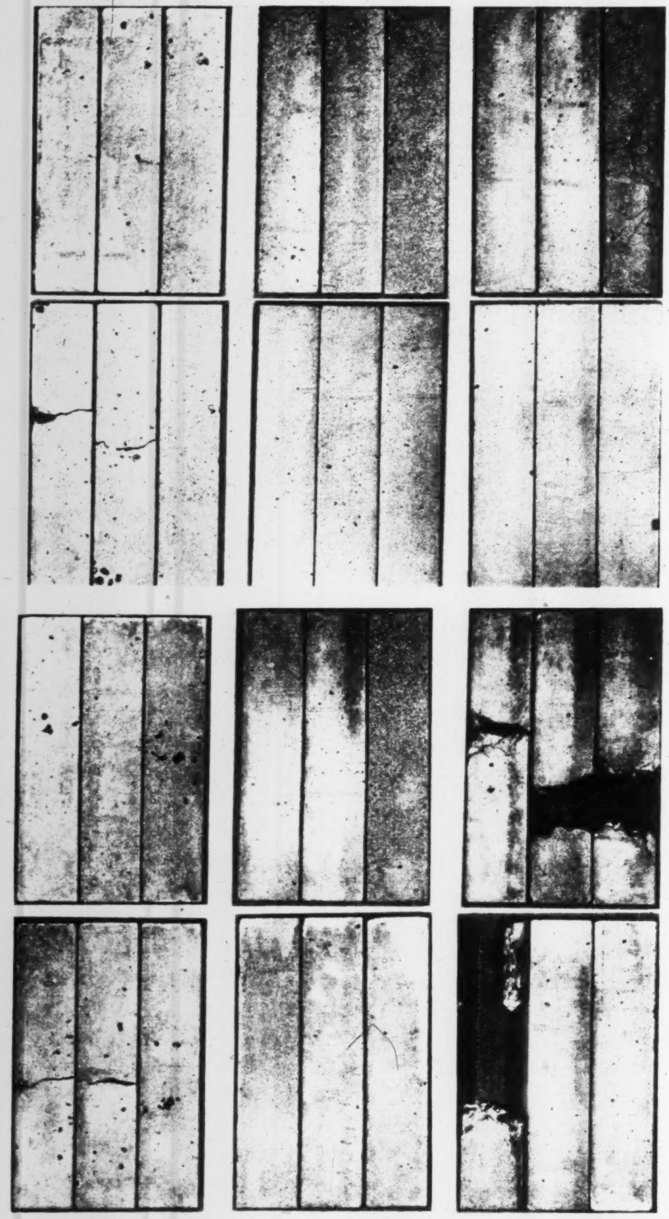
Type I Cement
No. 8
6.3 gal per sack
Type I Cement
No. 8
plus 0.015 per cent aluminum powder
6.2 gal per sack
Type I Cement
No. 9
6.3 gal per sack
Type I Cement
No. 10
6.2 gal per sack
No Slump
3 in. Slump
6 in. Slump

Fig. 7.—Effect of Consistency on Resistance to Severe Natural Weathering Side View of Beam Specimens after Exposure for 10 yr. (top edges on right).

Constant water-cement Ratio

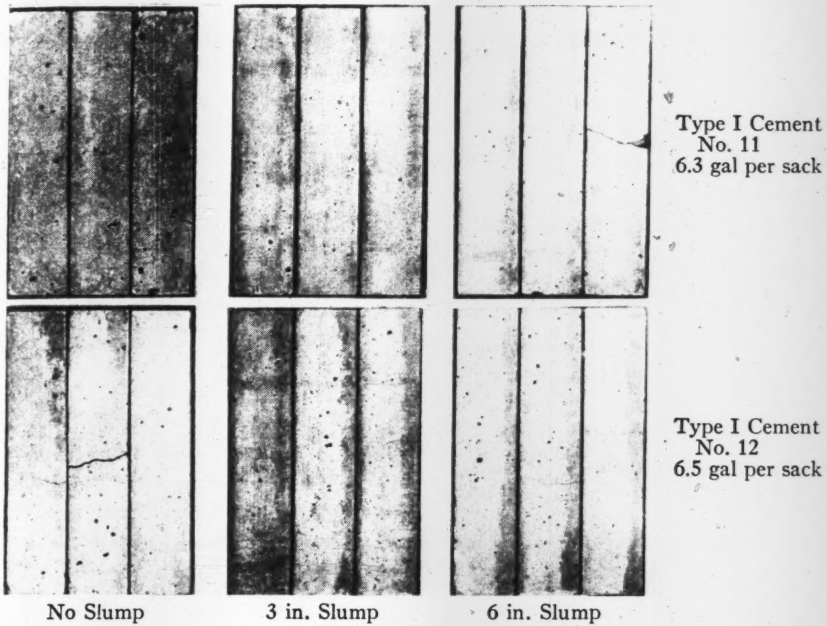

FIG. 7. (*continued*).

possible that other samples of these three types would show less surface defects. (Low strength the first winter must have been a contributory factor in deterioration of 4.5-sack concretes with this type IV cement sample.)

With minor exceptions cracks were the first sign of distress. After cracking, deterioration tended to progress more rapidly in the lean 4.5- sack mixes of Group A cements and the 6-in. slump concretes with Group B cements.

There are comparable 6-sack 3-in. slump concretes in both test groups. In the exposed concretes, which were all made with standard laboratory aggregate, this nominal 6-sack mix has shown best relative resistance to weathering.

The views in Fig. 7 prompt a new "optimum consistency" concept since, at $6\frac{1}{4}$ gal per sack fixed water-cement ratio, the 3-in. slump mixes are, in all cases, clearly distinguished as most resistant. It is also clear that the 6-in. slump mixes show a marked inferiority. The reason for the apparently lowered resistance of the "no slump" concretes is not clear. In some respects this appears to be akin to the inferior resistance of the concrete piles in the long-time Aberthaw[8] exposure tests which were made from mixes of dry consistency. The natural sea-water exposures at Boston were started in 1909; for the mix of intermediate proportiont $(1:2\frac{1}{4}:4\frac{1}{2})$ they found plastic and wes mixes least affected by 11 yr of exposure, but the pile cast from a very dry mix showed advanced spalling. Leaner and richer concretes showed the same tendencies but to a greater and lesser degree than the cited case.

With regard to Group B cements, four samples had total alkalies approximating 0.6 per cent while cement No. 12 had a high alkali content of 1.39 per cent. The aggregates used are not considered reactive, and this high alkali content did not appear to influence the results. Figure 7 shows the behavior of this cement to be similar to that of other type I cements since cracks in the stiff mix occurred the first winter and the other cracks were found after 9 yr exposure.

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[8] Aberthaw Tests of Concrete in Sea Water," Aberthaw Construction Co., Boston, Mass. (1921).

The natural exposure test shows some differences between cements in Group B and also distinguishes the air-entraining concretes in Group A. The limited scope of this project does not warrant drawing conclusions regarding the virtues of one cement type *versus* another or the superiority of one type I cement composition over another just because it has shown advantages in this unusual set of exposure conditions. The general durability indications shown by small beams in this natural exposure are reasonable and consistent with results of other investigations.[9, 10] The results obtained with several type I cements at fixed water-cement ratio are particularly interesting because they consistently show a tendency in several cases for lowered weather resistance when the placing consistency was very dry or very wet. It appears that further development of our test should be undertaken on a limited basis in an effort to determine the principles which should be followed to improve the weathering resistance of concrete.

Acknowledgment:

H. G. Collins and A. L. Bowman are members of our organization who made valuable contributions to the conduct of the test program.

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[9] F. H. Jackson, "The Durability of Concrete in Service," *Journal*, Am. Concrete Inst., Vol. 18, No. 2, Oct. 1946, p. 165.

[10] C. H. Scholer, "Studying the Durability of Concrete," *Journal*, Am. Concrete Inst., Vol. 7, No. 5, May-June 1936, p. 595.

DISCUSSION

Mr. Myron A. Swayze[1] (*presented in written form*).—The authors of this paper are to be complimented on their presentation of some very interesting data, not only the information on the effect of various cement types, cement contents of concrete, and concrete consistency on relative resistance to severe weathering, but also the deductions, which are possible from these data, on how tests should be conducted to provide dependable conclusions on the relative durability of different concretes.

Knowing the late J. C. Pearson, who instituted these two groups of tests, the writer imagines that the endeavor to devise a proper test method for durability was of equal if not of more importance to him than the particular results which were obtained in this series. Out of respect for him as a research man of high caliber, the writer would like to discuss the paper from the standpoint of its significance leading to a possible test method.

The data on reduction of sonic modulus, largely due to development of cracks, and on visible defects such as erosion, scaling, and spalling after 10 yr exposure are contradictory, especially for test specimens in the Group A tests, where seven cements of different types are compared in concretes of 4.5 and 6.0 sack cement contents. For example, in the following summary of the Group A tests, an unqualified comparison of the sonic modulus tests on type V cement would make it appear that the 4.5 sack mix is more durable than the 6.0 sack concrete for this cement, since all three beams of the weaker mix show high sonic modulus, while two out of three beams of the 6.0 sack mix have failed completely. Actually, all specimens of lean mix show surface attack by frost, while surfaces of the richer mix specimens are as yet unharmed.

SUMMARY OF TESTS: GROUP A.

Cement		4.5 Sack Concrete				6.0 Sack Concrete			
				1951 Beams				1951 Beams	
Type		Strength 28 Days	Sonic E 1941	Cracked	Scaled	Strength 28 Days	Sonic E 1941	Cracked	Scaled
I	No. 1	2950	3.80	2	1	6090	4.89	0	0
IA	No. 6	3280	3.75	1	0	5200	4.47	0	0
II	No. 2	2400	3.67	2	3	5470	4.59	2	0
IIA	No. 7	2880	3.72	0	0	5640	4.63	0	0
III	No. 3	3830	4.42	1	1	6920	5.13	3	0
IV	No. 4	1350	2.98	2	3	3290	4.10	1	0
V	No. 5	1950	3.75	0	3	5200	4.88	2	0
				8	11			8	0

It is apparent from a general view of this tabulation that there is little or no correlation between the tendency of the beams to crack under the conditions to which they were exposed and the strength of the concrete of which they were made, either as determined by compressive strength of moist-cured cylinders or by early sonic modulus tests on the beams themselves. Scaling tendency, on the other hand, as indicated by the authors' notes in Table III and photographs of the beams themselves in Fig. 6, increases with decreases in concrete strength, except for those beams made with air-entraining cement. No significant amounts of scaling were found on any of the richer mix specimens, with or without air entrainment.

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[1] Director of Research, Lone Star Corp., New York, N. Y.

If the appearance of visual defects in surfaces of the beams, such as scaling, erosion, and spalling is accepted as the true index of relative durability, then why has development of cracks in specimens in these tests not followed the same general pattern? The answer to this question lies in design of the shallow trays holding the specimens, in the spacing of beams in the trays, and in the manner in which water freezes and thaws in such an arrangement. Some of the details on tray design and placement not in the text of the paper have been kindly supplied by the authors; the remainder has been gleaned from a close examination of their Figs. 1 and 3.

The concrete trays for the specimens were cast directly in contact with the top of the concrete roof of an annex room used for sample storage at the Lehigh Research Laboratory. This room was unheated during the winters. The bottoms of the trays were relatively thick and were smoothly troweled. The sides were raised 2 in. above the tray bottoms, and were provided with a 45-deg taper towards the top inside edge. That no disintegration developed in the trays during the period of exposure is a sign of good durability.

Eighty-two beams were placed in the closest long tray shown in the foreground of Fig. 1. Spacing of this number of beams in two rows allows an average space of 2 in. between rows and an average space of about $\frac{3}{8}$ in. between beams. Close inspection of the photograph reveals a slight irregularity in spacing between beams or else a slight difference in the level of their top surfaces, which on the average project 1 in. above water level.

On incidence of the first freezing in such a system, the first ice to be formed is on the surface, usually around tray edges and between rows, and soon thereafter between beams. Freezing progresses downward, with water at the tray bottom being the last to freeze. During this freezing process, the continuous increase in volume due to transformation of water to ice must be relieved by an upthrust of the already frozen surface. At first, failures in flexure or in bond of the ice sheet to the tank and specimens furnishes relief for this growing pressure. However, as ice thickness approaches the maximum, the ice strength may exceed that of the concrete, in which case the beams themselves can either be broken in flexure or else can be raised bodily above the tank bottom.

The writer still remembers with chagrin the first freezing tests made at the Lone Star Research Laboratory in Hudson, in which this very thing happened. Our specimens were high-grade concrete, 28 days old, with dimensions 6 by 6 by 3 in. wide. Nine of these blocks were placed in a $6\frac{1}{4}$ by $6\frac{1}{4}$ by 36-in. steel can, square faces down. Identification tags wired onto the specimens caused a vertical separation of about a $\frac{1}{16}$ in. between blocks. The can was filled with water until the top block was covered and then set vertically in a brine tank at −20 F. Two cycles of freezing and thawing were completed and the specimens then removed and inspected, with the finding that every block except the one on the bottom of the can was broken into either two or usually four pieces. All of the pieces were completely sound.

The explanation for these failures is simple. The first water to freeze was that between the inside of the can and the block faces. The bond strength of the ice to can and to the specimens was greater than that of the concrete. Consequently, when the water between specimens froze, the pressure could not be relieved by passage around the specimens and therefore found release by smashing through them. The bottom block remained undamaged, due to the fact that the water beneath it froze before ice closed in at the sides. This block was, therefore, under no stress and remained intact.

In all following tests the blocks were placed in the cans in pairs, with the bottom rectangular 3 by 6-in. faces down. This provides down through the center of the can a water-filled space which is the last to freeze, thereby affording relief of all pressure. A bottom block is still laid flat, and two dummy half-blocks are placed at the top, to maintain uniform conditions in specimens actually under test. By judicious placing of newer, full-dimensioned blocks towards the bottom of cans and older, eroded specimens near the top, a slightly tapering pipe of water is maintained from bottom to top until freezing is complete. In consequence, fracture of specimens due to stress is very rare, while to the writer's knowledge a bottom block has never been lost.

Returning to flexural failure of the Lehigh specimens, thawing after a freeze also takes place from the top downward. That this process is not uniform is well illustrated by the author's Fig. 3, one row to the right being thawed on the surface, while the left-hand row is still frozen solid under snow and ice. Presumably, beams in the right-hand row may still be held firmly in ice at the bottom of the tank. Recurrence of freezing under such conditions can easily cause severe side thrust of ice forming between restrained beams, if freezing rates are different between successive pairs of beams, or if ice levels between pairs were different before freezing started at a uniform rate.

Calculation of some of these stresses developed by ice formation would be possible if some of the structural properties of ice were known. Unfortunately, there seems to be an amazing lack of knowledge on the flexural, compressive, and bond strength of ice. Until such knowledge is gained, even simple cases of specimen design to withstand physical stresses purely coincidental to frost action will be very difficult to solve. The best that can be done is to work with fairly sturdy specimens and to design the freezing container and test conditions so that the specimens will be free from stresses other than those exerted by typical frost action on exposed surfaces. Until this is done, the writer will continue to marvel at the assurance with which some accept the sonic modulus test as an index of durability under freezing and thawing.

Cracked specimens or cracked concrete in the field are more subject to the combined disintegrating action of water and frost than is whole, unbroken concrete. Cracks are always irregular and, once opened, are much more susceptible to stresses exerted by freezing water than are plane exterior surfaces. Figure 7, showing disintegration of 6-in. slump concrete which has started from simple cracks, is an excellent illustration of this. Little imagination is required to picture the steady breaking away under successive freezings of one particle after another of mortar and aggregate from what was originally a single break to what has become a wide space representing totally disintegrated concrete.

The writer believes consideration should be given to what is to be determined in running laboratory tests on freezing and thawing. If it is to measure the disintegrating action of frost on the top surfaces of wet concrete pavements, then the specimens exposed must be handled in a manner that will not subject them to stresses incidental to freezing of water around them. The specimens involved in the present instance were not so protected. On the other hand, if it is intended to include these stresses as part of the over-all picture, simulating the heaving effect of frost in a wet subgrade under the pavement, then each specimen should be subjected to exactly the same conditions, with some preliminary research on the structural properties of ice at various temperatures below that of freezing. It is apparent that conditions in the Lehigh tests were not constant for all specimens.

These remarks are not intended at all as a disparagement of this report or of the method employed. Frequently far more is learned from failures than from successes. If there is ever to be a standard method for conducting freezing-and-thawing tests, there must be more frank and instructive papers, such as this one.

MR. WALTER H. PRICE.[2]—I am particularly interested in the inferior durability for the higher slump concrete. Is there an explanation such as less entrained air because of ease of compaction that could account for this?

MR. S. B. HELMS (*author*).—There was no air entrainment in the group of cements to which Mr. Price refers. But the technique used to consolidate the specimens could have resulted in a little bit of overmanipulation. I believe that the specimens were rodded in three layers, but the rodding was minimized according to the consistency. The tendency would have been to reduce the number of roddings in the wetter mixes so there would be less movement of coarse aggregate.

MR. BRYANT MATHER[3] (*by letter*).—The writer would like to discuss briefly the comment by Mr. Swayze that "unfortunately, there seems to be an amazing lack of knowledge on the flexural, compressive, and bond strength of ice." It seems that there is perhaps an even more amazing lack of realization of the influence of these factors on freezing-and-thawing tests and lack of realization of the need for such knowledge. Since Mr. Swayze has cited the need for such data, it might be pointed out that sections of the American Geophysical Union are concerned with such problems as the behavior of natural ice, the physical constants and deformation of ice, and the mechanics of glacier flow and that the Snow, Ice, and Permafrost Research Establishment of the Corps of Engineers, U. S. Army, has issued a number of reports.[4]

A number of references are listed at the end of this discussion; several are briefly abstracted.

Wilson and Horeth (**1**)[5] have performed tests on natural ice from Lake Michigan and on artificial ice and found an indicated tensile strength of about 200 psi. These tests also indicated a marked increase in tensile strength with decreasing temperature, and increase from about 180 psi at 32 F to about 260 psi at −9 F. The shear strength was found to be about 100 psi and was not indicated to vary with temperature.

Northwood (**2**) made sonic determinations of the elastic properties of ice, obtaining values of 9.8×10^{10} dynes per sq cm for Young's modulus and 0.33 for Poisson's ratio. These tests were made at −15 C on natural ice from the Ottawa River and on artificial ice. He concludes that it would appear that ice is highly susceptible to thermal effects, at least in the range −30 to 0 C.

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[3] Engineer, Concrete Research Division, Waterways Experiment Station, Corps of Engineers, U. S. Army, Jackson, Miss.

[4] "Review of the Properties of Snow and Ice," *SIPRE Report 4*, University of Minnesota, March, 1951, 156 pp.; "Annotated Bibliography on Snow, Ice, and Permafrost," *SIPRE Report 12*, Library of Congress, Sept., 1951.

[5] The boldface numbers in parentheses refer to list of references on p. 1203.

Matsuyama (**11**) found that the modulus of rigidity and Young's modulus of ice were small as compared to the elastic constants of metals and that elastic fatigue after repeated torsion was quite pronounced.

Boyle and Sproule (**12**) made tests to determine Young's modulus of ice and found that it seemed to decrease slightly with a decrease in the temperature of the ice; crystal orientation apparently had no effect.

Finlayson (**13**) tested 3 by 3-in. specimens in the temperature range −10 F to + 30 F and found no temperature dependence. At temperatures below 0 F the values were greater when the load was applied rapidly. The average values were: 114 psi perpendicular to the crystals, 98 psi parallel to the crystals. Artificial ice showed about 80 per cent of the shear strength of river ice. Compressive strength of river ice at 11 F was 1800 psi parallel to the crystals, 1050 psi perpendicular to the crystal plane. Tensile strength of briquettes molded from water ice was 136 psi and from snow and water ice, 103 psi.

Bell (**14**) reports tests on ice frozen in "cement" molds and cut from blocks as having shown tensile strength of 120 psi; compressive strength of 590 and 654 psi, parallel and perpendicular to the crystals, respectively.

The items abstracted above are those that are less accessible. The most comprehensive discussions of these subjects are in the *SIPRE Report 4*[4] and the excellent books by Dorsey and Barnes (**3** and **6**).

MR. HELMS (*authors' closure*).—When it was found that Mr. Swayze was interested in the results of our natural weathering tests, his discussion was solicited by the authors who realized that forthright criticism would be of considerable value to us and others who are interested in the study of concrete durability. His short summary of Group A tests serves to emphasize the fact that sonic measurements cannot be depended upon entirely to evaluate the performance of the small beams. However, the sonic method did provide the substantial amount of information which is given in Fig. 5. No correlation of sonic data with general performance was found except that continued measurements were possible on undamaged specimens; for this reason the condition of specimens, after exposure, was shown.

It is perhaps best that the experience with the Lone Star slab specimens[6] should be repeated as a precaution to others since it proves that specimens can initially suffer severe damage when frozen under extreme conditions of restraint. In the case of natural freezing of water in the Lehigh trays, the progression of ice formation as traced by Mr. Swayze is valid and the last stage is known to be a disruption of the frozen surface between the rows of beams along the center line of the tray which also forms a channel for the relief of pressure. There is no question that the beams are subjected to some flexural stresses in the process of freezing and thawing, for this is a part of the severity of the exposure. Reference to Tables III and IV will reveal that, with minor exceptions, only certain beams from the dry consistency, 5-sack Group B concretes were cracked after two full winters of exposure. The cited dry-mix specimens were all stored in the long tray shown in the background of Fig. 1. It is of interest to reconsider this performance in view of the criticism which was made and possibly to acquire a different perspective of the events which occurred.

To refer back to the original objectives, it was expected that some specimens would fail and deteriorate, but the manifestation of cracking was not expected. It is very probable that the differences between specimens in a subgroup may not be attributed to some slight differences due to their position in the exposure trays but rather to inherent differences in the specimens themselves. Can three specimens, made from independent similar concrete batches, be expected to fail in the same number of accelerated laboratory freezing-and-thawing cycles?

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[6] M. A. Swayze, General Discussion, "Symposium on Freezing-and-Thawing Tests of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 1248 (1946).

Despite some inconsistencies it is possible to enumerate a few general relationships based on the data in Tables III and IV:

1. Incidence of cracks in Group A Cements exposed 6 winters:

Cement Type...	I	IA	II	IIA	III	IV	V	Total Cracks
4.5-sack mix......	2	1	3	0	1	2	0	9
6-sack mix........	0	0	0	0	0	1	1	2

2. Incidence of cracks in Group B type I Cements exposed 6 winters:

Cement No...........	8	8 + al	9	10	11	12	Total Cracks
No slump 5 sacks......	2	2	0	2	0	2	8
3-in. slump 6 sacks.....	0	0	1	1	0	0	2
6-in. slump 6.3 sacks...	1	0	2	1	0	0	4

3. Item 1 above can be further analyzed by reference to Fig. 5. The diagrams of Sonic *E* show strength gains for all Group A cements in 4.5- and 6-sack mixes during the first winter and no cracks occurred. If excessive flexural forces were exerted on the beam specimens in the natural winter freezing process, most of these specimens should have cracked when their strength level was at its lowest point, that is, during the first winter. Instead, very little cracking occurred in this test group until the specimens had been subjected to exposure for several winters. This fact does not appear to fit any analysis or theory which presupposes that the cracking of the specimens can be simply attributed to the force of freezing water as the sole influence.

Crack incidence must not necessarily correlate with surface defects in order to have significance, and we believe that any simplified explanation of the progression of deterioration at the locale of a crack should be given careful study. Such an explanation should fit practically all the cracked specimens in the Lehigh test series. It must be admitted that the cracked specimens made from dry mixes of Group B cements, which are shown in Fig. 7, have not conformed to this concept since the progressive deterioration of these early cracks has been extremely slow.

The discussion of the effects of partly melted snow, as pictured in Fig. 3, has called attention to a possible clue to cracking. It is of interest to repeat that cracks started at the top of the specimens. This is evident in all illustrations of Figs. 6 and 7. Each row of specimens in turn was subjected to the effects of the melting process and therefore should have received essentially the same treatment. There is no evidence that side thrust from freezing of water between beams was a factor in cracking. The consistent fact that cracks opened at the top of beams, combined with the observation that in numerous cases cracks progressed downward over a long period of time—in fact, some cracks were healed and never progressed—suggests that cracks were not due to the pressure of ice formation under beams with ends restrained. It seems more reasonable to conclude that the thawing step was more conducive to cracking than the freezing since temperature differentials in the specimens were greatest during the thawing step.

In stating certain preferences for setting up a test procedure involving freezing and thawing, the prepared discussion declares that specimens should be protected from forces incidental to water freezing around them. This is particularly desirable when it is realized that specimens restrained by bond to ice can be subjected to tremendous pressures. Undesirable test conditions of this sort would lead to the fracture of every specimen under test and there would be little discrimination between specimens or test conditions, just as other conceivable conditions of extreme severity would impair discrimination. It is probably unfair to expect any natural weathering test to meet the same uniformity standards which should be set for accelerated laboratory techniques. In utilizing the forces of nature, some differences in sun, wind, and frost are to be expected, but these were minimized to substantial degree when the tray type of exposure was devised.

The scope of the Group A tests precludes any strict comparison of cement types since this exploratory series included only 1 cement of each type. An improvement due to air entrainment is evident, however, and the preceding tabulation of 6-yr status (item 1) shows the richer mixes more durable than the leaner mixes. Fortunately the scope of the Group B test series was broad enough to produce some particularly interesting information on the effect of consistency on the durability of concrete. The arrangement of data in the paper enables the reader to appraise the status of specimens in the intervening years. The illustration of appearance of specimens at age 10 yr should not be interpreted to signify that the authors believe that the specimens should be rated solely on the basis of the 10-yr status.

These remarks will be concluded by mentioning briefly two additional references pertinent to this discussion:

1. In a comprehensive report of paving concrete studies, F. H. Jackson[7] found a marked tendency for flexural strength of beams and slabs to fall off for dry mixes. He concluded that concrete of medium consistency (2 to 3 in.-slump) was essential to concrete uniformity and freedom from honeycomb. The recommendation was made that use of paving mixes of less than 2-in. slump should be avoided. This finding is in agreement with the results of our Group B tests.

2. At an American Concrete Institute convention session devoted to Concrete as an Architectural Material, R. W. Carlson[8] discussed some of the general aspects of concrete durability testing and offered comment on some causes of cracking in concrete. This short article by Carlson is recommended for another reading because it shows a perspicacity and breadth of viewpoint that all investigators who study concrete should appreciate.

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[7] F. H. Jackson and W. F. Kellerman, "Studies of Paving Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part II, p. 457 (1931).

[8] R. W. Carlson, "Remarks on Durability of Concrete," *Journal*, American Concrete Institute, Vol. 10, No. 5, p. 359 (1939).

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(2) T. D. Northwood, "Sonic Determination of the Elastic Properties of Ice," *Canadian Journal of Research*, Vol. 25, Sec. A, pp. 88–95 (1947).

(3) N. Ernest Dorsey, "Properties of Ordinary Water Substance," Reinhold Publishing Co., New York, N. Y., 1st Edition (1940).

(4) Henry Moseley, "On the Mechanical Properties of Ice," *Philosophical Magazine*, Vol. 39, pp. 1–8 (1870).

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(7) Frank Press and Maurice Ewing, "Propagation of Elastic Waves in a Floating Ice Sheet," *Transactions,* Am. Geophysical Union, Vol. 32, No. 5, Oct. 1951, pp. 673–678.

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(11) Motonori Matsuyama, "On Some Physical Properties of Ice," *Journal of Geology,* Vol. 28, Oct.–Nov., 1920, pp. 607–631.

(12) R. W. Boyle and D. O. Sproule, "Velocity of Longitudinal Vibration in Solid Rods (Ultrasonic Method) with Special Reference to the Elasticity of Ice," *Canadian Journal of Research,* Vol. 5, Dec. 1931, pp. 601–618.

(13) John N. Finlayson, "Tests on the Shearing Strength of Ice," *Canadian Engineer,* Vol. 53, July 1927, pp. 101–103.

(14) George G. Bell, "Results of Experiments on the Strength of Ice," Maine Soc. of Civil Engineers, Vol. 1, pp. 41–46 (1911).

STUDIES OF ABNORMAL EXPANSION OF PORTLAND CEMENT CONCRETE*

By A. D. Conrow[1]

Synopsis

Severe cracking of portland cement concrete has been observed in the Central Great Plains region of the United States. In most structures showing distress, the concrete aggregate was a siliceous sand-gravel common to the region. Investigations were conducted which led to the discovery of conditions under which a very severe abnormal expansion occurred. These conditions were within the range possible under natural exposure of concrete in service in the localities where the severe cracking was observed.

Studies were made to determine the exposure conditions under which the abnormal expansion would develop most rapidly in order that means for inhibiting or preventing it might be developed.

It was found that conditions quite effective for promoting the abnormal expansion were within the range of natural exposure of much concrete in service in the region in which concrete in distress has been observed.

Studies were instituted to determine whether combinations of the sand-gravel aggregate and portland cements in general would exhibit the abnormal expansion when subjected to the conditions found to promote its development.

Studies then undertaken were of the nature of a search for means to inhibit or prevent the abnormal expansion in cement-aggregate combinations in which it would develop if no preventive measures were applied.

In an area roughly including western Kansas, Nebraska, and eastern Wyoming, the principal sources of concrete aggregates are the sand-gravel deposits in the beds and watersheds of the Platte, Republican, Kaw, and Arkansas Rivers. All of these streams have their headwaters in the eastern slope of the Rocky Mountains and their sand-gravel deposits are similar in nature.

It was not until the late 1920's that this aggregate was extensively used as aggregate in portland cement concrete and at that time was considered to have excellent qualities for this use. In many localities the material economically available contained an excess of fine sizes to yield concrete of satisfactory strength and density with a minimum of portland cement. Due to the fine gradation, many structures were built of concrete having a somewhat high cement content. Much of this type of concrete was used in highway bridges and pavements. Extensive use of these materials in concrete continued thereafer. About five to seven years after extensive use started, the concrete in many of the structures developed serious cracking which in many cases required extensive repairs on bridges and which greatly reduced service life of the concrete in pavements.

Not long after this development had

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Research Engineer, Ash Grove Lime & Portland Cement Co., Chanute, Kans.

attracted attention, cement-aggregate reaction expansion was discovered in structures in California and at the Parker Dam on the Colorado River. Investigation by the California Highway Department (1)[2] and the United States Bureau of Reclamation (2) led to a conclusion that sodium and potassium alkalies in the cement caused the trouble, and these agencies and others set limits on the akali content of cements to be used where a reactive aggregate might be used. Cement with alkali contents at or below the limits set were difficult to produce at many manufacturing plants. Cement manufacturers and some engineers were not convinced that low alkalies in cement would solve the problem, especially that involving the sand-gravel aggregate heretofore discussed. It was quite definitely demonstrated that the expansion in sand-gravel concretes was not consistently related to the alkali content of the cement and that the use of low-alkali cement would not insure freedom from expansion troubles.

TABLE I.—GRADATION OF AGGREGATES.

	Per cent Retained on Square Mesh Sieves									
Sieve size.....	¾	½	⅜	4	8	16	30	50	100	Fineness modulus
Sand-gravel...	0	0	0	9	30	52	83	96	99	3.80
River sand...	0	0	0	2.5	14	33	61	94	99	3.03
Crushed stone	0	62	75	100	...	...	...	...	...	6.75

It was believed that portland-cement concrete having as aggregate the siliceous material with rather fine gradation would exhibit greater volume changes with variations of temperature and moisture than would concretes containing larger size limestone coarse aggregates. Accordingly, beam specimens, 3 by 3 by 11 in., were prepared from a series of concretes using a number of different types of cement and two types of aggregates as follows: (1) a Kaw River sand-gravel mixed aggregate; (2) a river sand-crushed limestone aggregate with 1 in. maximum size. The ratio of stone to sand by weight was 60 to 40. The beam specimens had gage points in ends placed so that the bedded ends of the gage points were 10 in. apart. The proportions for each aggregate were adjusted so that a slump as near as practical to 6 in. was obtained using 54 lb of water per bag of type I portland cement. All mixtures of solids with a given aggregate were then made the same. There was a small variation in water requirements to obtain the slump selected among the various types of cement in the series.

TABLE II.—CONCRETE MIXTURES.

	Sand-Gravel Concrete	Sand-Limestone Concrete
Cement, lb........................	94	94
Sand, lb........................	0	208
Sand-gravel, lb........................	394	0
Crushed stone, lb........................	0	327
Water, lb........................	54[a]	54[a]

[a] Water content of mixtures with various cements varied slightly with the character of the cement since the concretes were mixed to a consistency showing a slump of 6 in. ± ½ in.

This arrangement resulted in cement contents in the concretes as follows:

Sand-gravel concrete........	7 sacks per cu yd
Sand-limestone concrete.....	6 sacks per cu yd

The gradation of the aggregates is shown in Table I and the concrete mixtures in Table II.

These concretes were cured in water at standard curing temperature of 73 ± 3 F, for a period of about four months before tests for volume change were undertaken. The concrete beam specimens were prepared and cured with the object in view that after an ample curing period they would be subjected to a range of temperature and moisture variations measuring length changes throughout the range. To carry out this objective, after the curing period, the beams were subjected to the following schedule, which will be designated as schedule A.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1222.

SCHEDULE A

1. Measured for length at 70 F in a saturated condition.
2. Placed in a temperature-controlled water bath with bath temperature set at 100 F. Length measurements made on two consecutive days.
3. Bath temperature raised to 120 F and length measurements made as for item 2.
4. Bath temperature raised to 140 F and length measurements made as before.

TABLE III.—LENGTH CHANGES IN CONCRETES.[a]

	Sand-Gravel Concrete	Sand-Limestone Concrete
Per cent length increase during 120 days water curing	0.0088	0.0022
Length change, in. per in. per deg Fahr, saturated concrete	0.0000054	0.0000043
Length change, in. per in. per deg Fahr, dry concrete	0.0000065	0.0000040
Per cent length increase found when concrete returned to 70 F after heating in water	0.027	0.017
Per cent length change saturation to dry at 70 F	0.065	0.034

[a] Values in this table are for type I portland cement.

5. Bath temperature raised to 160 F and length measurements made as before.
6. Bath temperature lowered to 70 F, length measurements made as before.
7. Bath temperature lowered to 32 F, length measurements made as before.
8. Returned to 70 F water storage.
9. Removed from water storage, length measured, and placed in 70 F air storage where they remained until length became stable.
10. Placed in temperature-controlled oven, air-set at 80 F in which air was circulated through a bed of calcium chloride to remove moisture. Daily length measurements made until length became stable.
11. Oven temperature raised to 100 F and measurements made as when set at 80 F.
12. Oven temperature raised to 120 F and measurements made as before.
13. Oven temperature raised to 140 F and measurements made as before.
14. Oven temperature raised to 160 F and measurements made as before.
15. Oven temperature reduced to 120 F and measurements made on two consecutive days.
16. Oven temperature reduced to 80 F and measurements made on two consecutive days.
17. Placed in 70 F air storage for a 28-day period. Length measurements at start and end of period.
18. Returned to standard-temperature water storage. Length measurements for water storage periods of 1 day, 3 days, 7 days, 28 days, and at 28 day intervals for a period of several months.

During the progress of schedule A to item 18, which involved return to standard-temperature water storage, there were no unexpected developments. The concretes showed relative length changes as listed in Table III.

The results show that volume changes due to temperature and moisture changes are higher for sand-gravel concrete than for sand-limestone concrete, but the magnitude of the changes is not sufficient to cause severe deterioration of the sand-gravel concrete but the sand-gravel concrete should show a greater tendency to crack than the sand-limestone concrete.

Item 18 of schedule A was included to learn whether concrete, after the thorough drying given, would return to its initial volume. The concrete specimens from both types of aggregate when returned to standard-temperature water storage had returned to their initial length within 24 hr and continued to expand to an extent greatly exceeding any length changes observed previously.

The greatest length gain above initial length observed in previous exposures was at 160 F in a water-saturated condition, and it did not exceed 0.085 per cent for sand-gravel concrete and 0.06 per cent for sand-limestone concrete. The length gain under conditions of item 18 reached values as follows within 90 days:

	Length Gain, per cent	
	Sand-Gravel Concrete	Sand-Limestone Concrete
Type I portland cement	0.42	0.19
Type III portland cement	0.83	0.66

The expansions observed here, especially those of concrete made with sand-gravel aggregates, were so great in comparison to those observed for the most extreme conditions of temperature and water saturation that further investigation of the phenomenon seemed necessary. The expansion of sand-gravel concrete made with type III cement reached values approaching 1 per cent and that made with type I cement approached 0.5 per cent. The sand-limestone concrete showed considerably lower expansion, but values when type III cement was used were quite high. The river sand used in the sand-limestone concrete was from the same river bed as the sand-gravel, thus the expansion of the sand-limestone concrete may be considered caused by the presence of the siliceous sand from the same source as the sand-gravel.

In later tests of sand-cement mortars containing the river sand, expansions under conditions of item 18 were as follows:

With type I portland cement, per cent expansion	0.96
With type III portland cement, per cent expansion	1.42

It is not likely that the alkali content of the cements used played much part in the high expansions observed. The sodium equivalent alkali contents of both cements were below 0.60 per cent, and under the long curing in frequently changed water and heat treatment in saturated condition practically all soluble alkali would have leached out long before the abnormal expansion started.

Many Cements Tested:

After observation of the phenomenon just described, various brands of portland cement obtainable in the central United States were obtained from dealer stocks. The list of cements obtained included 26 cements from 22 mills, including 4 white cements and 2 high-early-strength cements. Kaw River sand-gravel mixtures were prepared with proportions as given for the sand-gravel mix in Table II from which 3 by 3 by 11-in. beams were molded then subjected to schedule A. All concretes showed abnormal expansion under item 18 of schedule.A but to varying degrees.

The expansions obtained and their relation to cement compounds, oxides, and finess are shown in Fig. 1. In this chart the cements are arranged in order of magnitude of the expansion observed. A study of this chart indicates no consistent relationship of degree of expansion to any particular constituent, the alkali content, or the specific surface, except that all cements with quite high specific surface show expansions among the higher values but some cements with low specific surface also show expansions among the higher values. This investigation demonstrated that all concretes made with a combination of the sand-gravel aggregate and any of the brands or types of portland cement obtained for use in this series of tests would develop abnormal expansion but to variable degrees.

Having learned that the development of the abnormal expansion of concrete containing the sand-gravel aggregate would occur when many brands and dif-

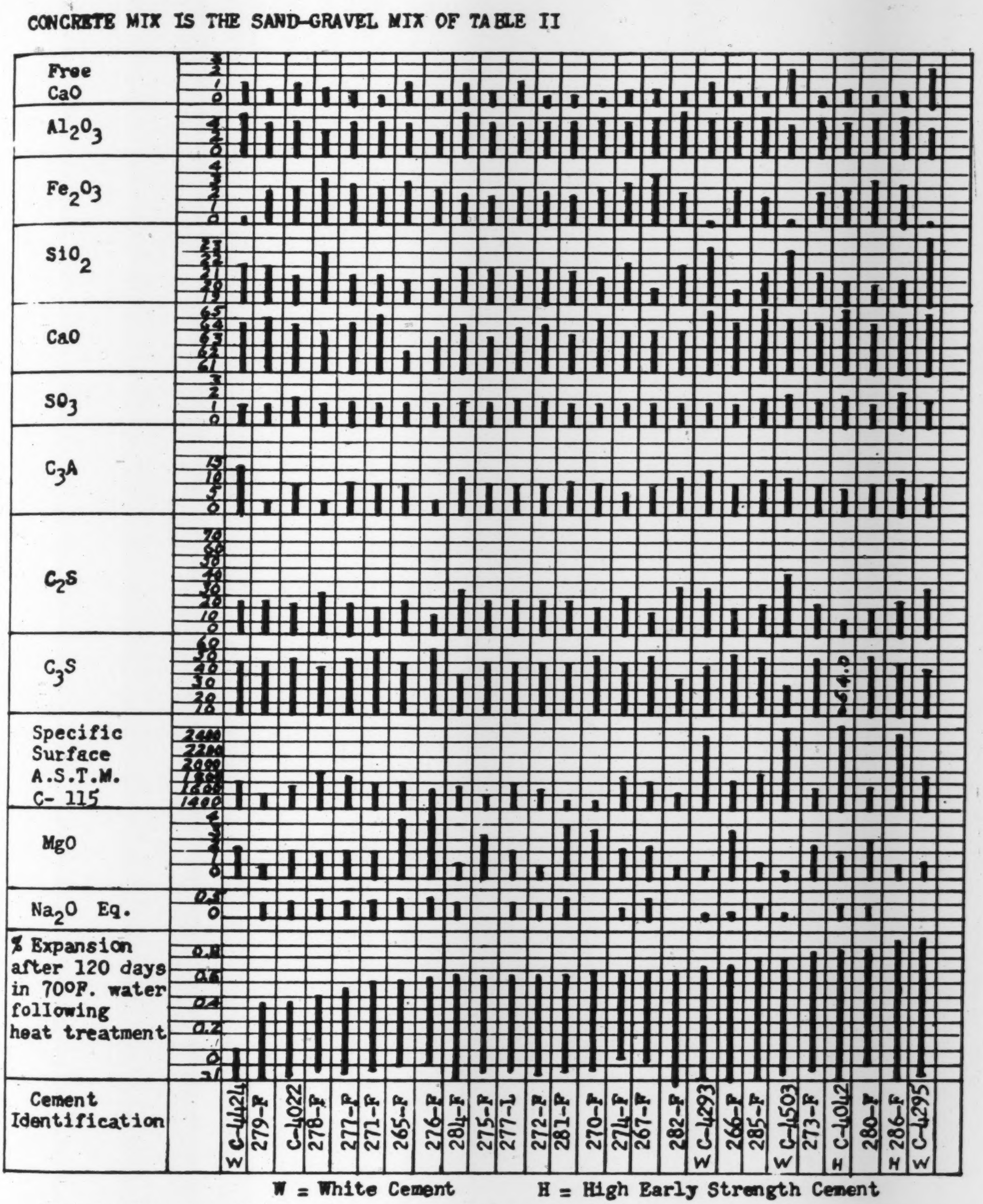

FIG. 1.—Bar Chart Showing Abnormal Expansion of Sand Gravel Concrete and Its Relation to Cement Compounds, Oxides and Fineness, when Tested Under Schedule A.

Concretes contain Kaw River aggregate and 26 cements from 22 mills, including 4 white cements and 2 high early strength cements. The letters *W* and *H* at the base of the chart indicate white and high early strength cements, respectively.

ferent types of portland cement were used, investigations were continued, seeking to learn whether the abnormal expansion would develop under exposures similar to that of concrete in service in structures. Investigations in this phase involved determination of effect of curing time and degree of heat treatment, also investigations to determine whether the time required to develop significant expansion could be shortened.

During the course of these investigations, information on the effect of different exposures in producing abnormal expansion was obtained as follows:

Exposure 1—Exposure according to schedule A.

Exposure 2—Standard-temperature curing in water seven days, then heat treatment at 140 F, then continuous standard-temperature water storage to observe growth.[3]

Exposure 3—Standard-temperature curing in water 14 days, then heat treatment at 140 F, then continuous standard-temperature water storage to observe growth.[3]

Exposure 4—Standard-temperature curing in water 28 days, then heat treatment at 140 F, then continuous standard-temperature water storage to observe growth.[3]

Exposure 5—Standard-temperature curing in water 90 days, then heat treatment at 140 F, then continuous standard-temperature water storage to observe growth.[3]

Exposures 6 to 9, inclusive—Same as exposures 2 to 5, except heat treatment at 120 F.[3]

Exposure 10—Same as exposure 4, except heat treatment at 130 F.[3]

Exposure 11—Standard-temperature fog-room curing 7 days, 21 days laboratory air at 70 to 77 F and 50 to 70 per cent relative humidity, then to standard-temperature water bath 48 hr. Then to a cycle as follows: 8 hr in 130 F water, then 16 hr in standard-temperature water, repeating the cycle daily except Sundays and holidays which time, specimens remain in standard-temperature water storage.

Exposure 12—Same preliminary curing as exposure 11; cycle as follows: 8 hr in 130 F drying oven followed by 16 hr in standard-temperature water storage repeating cycles for a period of 1 yr (C. H. Scholer's cycle) (**3**).

Exposure 13—Water curing for seven days at standard temperature followed by heat treatment at 160 F, then continuous standard-temperature water storage to observe growth.[3]

Exposure 14—Cured 24 hr in molds at standard temperature followed by 24 hr standard-temperature water storage, then to heat treatment as follows: 5 hr over boiling water as for soundness of pats in soundness of portland cement; 20 hr in drying oven at 105 C; cooled slowly to standard temperature, then to continuous storage in standard-temperature water to observe growth.

Exposure 15—Preliminary curing and heat treatment same as exposure 10 followed by outdoor storage bedded in earth with troweled surface flush with surface.

Exposure 16—Standard-temperature curing in fog room 90 days followed by heat treatment at 130 F, then continuous standard-temperature water storage to observe growth.[3]

Exposure 17—Standard-temperature curing in water 28 days followed by heat treatment at 130 F then to 130 F water storage for length readings for a 1-yr period.[4]

Exposure 18—Preliminary curing same as exposure 4, then heat treatment of one day at 130 F in water followed by drying in 130 F for four to five days, (that required to reach a stable weight). Then continuous standard-temperature water storage to observe growth.

Exposure 19—Same as exposure 18 except heat treatment of two days at 130 F in water followed by oven drying at 130 F for four to five days (that required to reach stable weight), followed by continuous storage in standard-temperature water to observe growth.

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[3] For these exposures the heat treatment was as follows: seven days in water at the temperature designated, followed by seven days in a drying oven at the temperature designated.

[4] The actual temperature of specimen should be recorded when length readings are taken so that correction to 70 F may be made if desired.

Exposure 20—Standard-temperature curing in fog room 7 days, then to outdoor storage imbedded in earth.

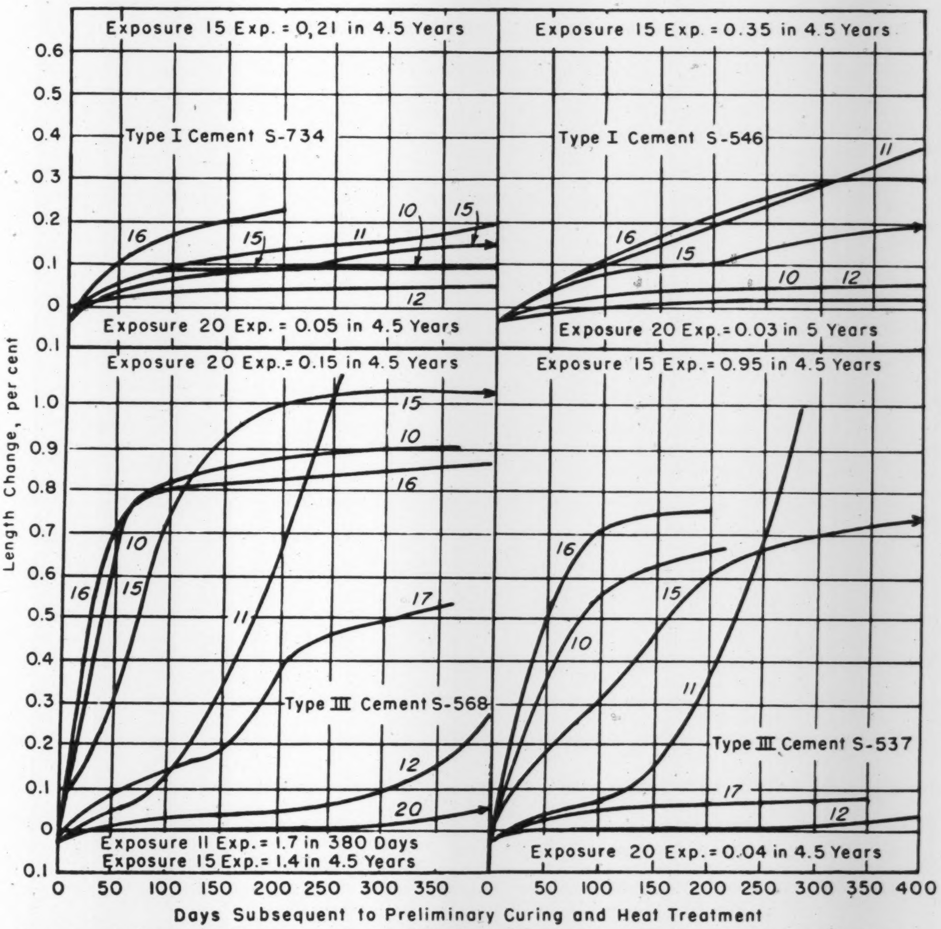


FIG. 2.—A Group of Expansion Curves Obtained from Various Exposures During Exploratory Tests for Development of a Standard Procedure.

Curves for exposures giving results of minor interest are not shown.
Exposure 10—28 days standard cure, 130 F heat treatment, standard temperature in water thereafter.
Exposure 11—7 days fog, 21 days air, alternate 70 F and 130 F water thereafter.
Exposure 12—7 days fog, 21 days air, alternate 70 F water and 130 F air thereafter.
Exposure 15—28 days standard cure, 130 F heat treatment, outdoor storage thereafter.
Exposure 16—90 days standard cure, 130 F heat treatment, standard temperature in water thereafter.
Exposure 17—28 days standard cure, 130 F heat treatment, 130 F water storage thereafter.
Exposure 20—7 days standard temperature fog then to outdoor storage thereafter.

During the course of the program of exposures listed, the following information was obtained:

1. The degree and rate of development of abnormal expansion varied with the length of standard-temperature wet-curing time. The minimum curing time found practical for research testing purposes was 28 days.

2. An accelerated curing by 5-hr steam test inhibited the abnormal expansion.

3. The minimum temperature of heat treatment practical for research testing

in a search for means of preventing or inhibiting the action was found to be 130 F.

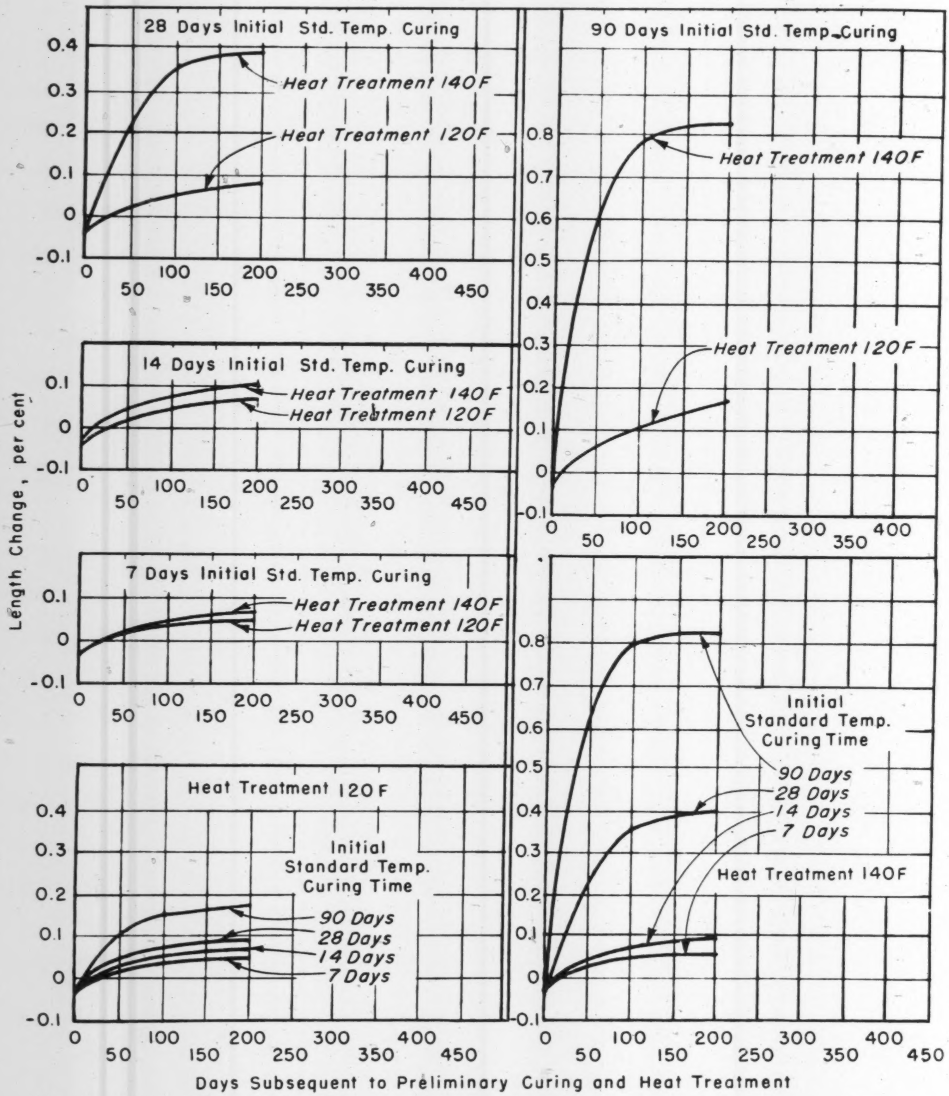


FIG. 3.—Curves Showing the Effect of Initial Standard Temperature Curing Time and Temperature of Heat Treatment on Abnormal Expansion of Reactive Sand Gravel Concrete.

4. With some cements abnormal expansion would develop after heat treatment water-saturated only, but it was more certain to develop if the concrete was subjected to the drying treatment following the heat treatment saturated.

5. Abnormal expansion developed with heat treatments as low as 120 F but did not develop to a sufficient magnitude to be considered suitable for tests to study the phenomena and for develop-

ment of means for inhibiting or preventing the expansion.

develop as would develop in standard-temperature water storage.

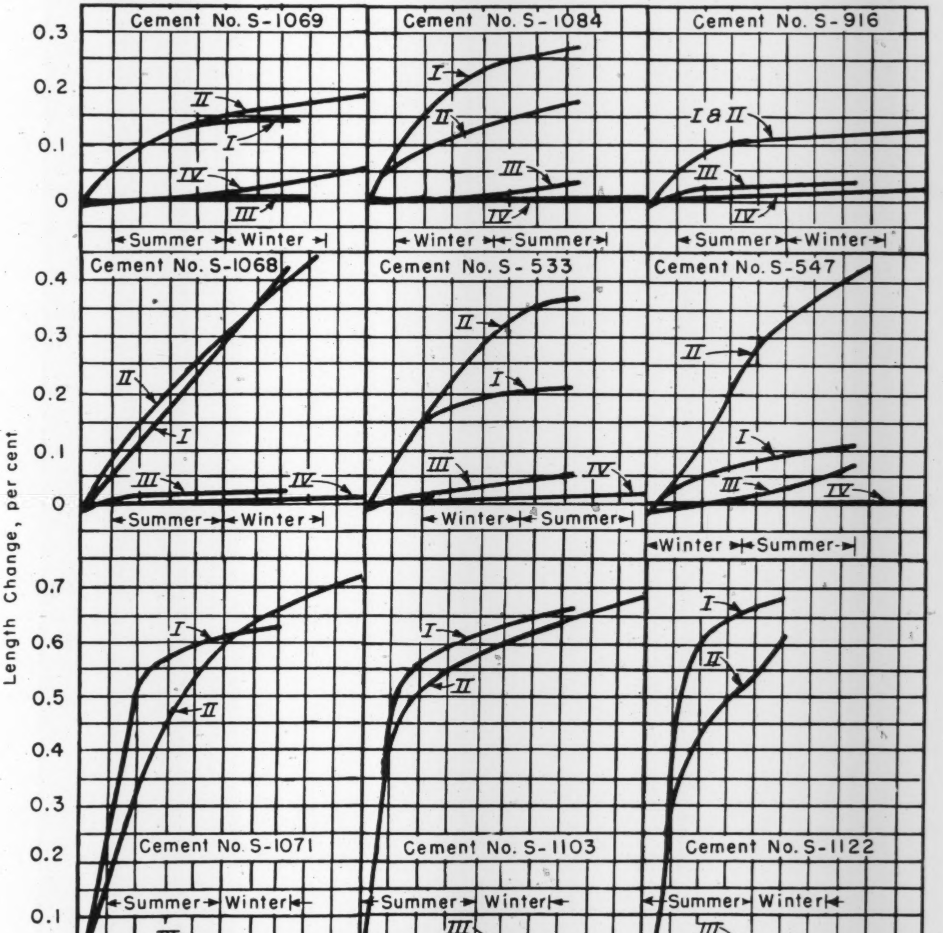


FIG. 4.—A Group of Curves for Tests of Various Type I Cements Showing Low, Medium, and High Expansion Tendencies.

The chemical analysis, compound composition, and specific surface of the cements may be found in Table IV.
Curve I—28 days standard cure, 130 F, heat treatment, standard temperature water thereafter (adopted exposure).
Curve II—28 days standard cure, 130 F heat treatment, outdoor exposure thereafter.
Curve III—7 days standard cure, 21 days air cure, alternate 70 F water and 130 F air thereafter.
Curve IV—7 days in standard cure, outdoor weather exposure thereafter.

6. Continued storage at 130 F in water after heat treatment at 130 F did not cause as great abnormal expansion to

7. The abnormal expansion developed to a high degree in outdoor storage after heat treatment at 130 F.

8. The abnormal expansion did not develop in continuous storage in standard-temperature fog room if no heat treatment was given. Observations were continued over a period of 7 yr.

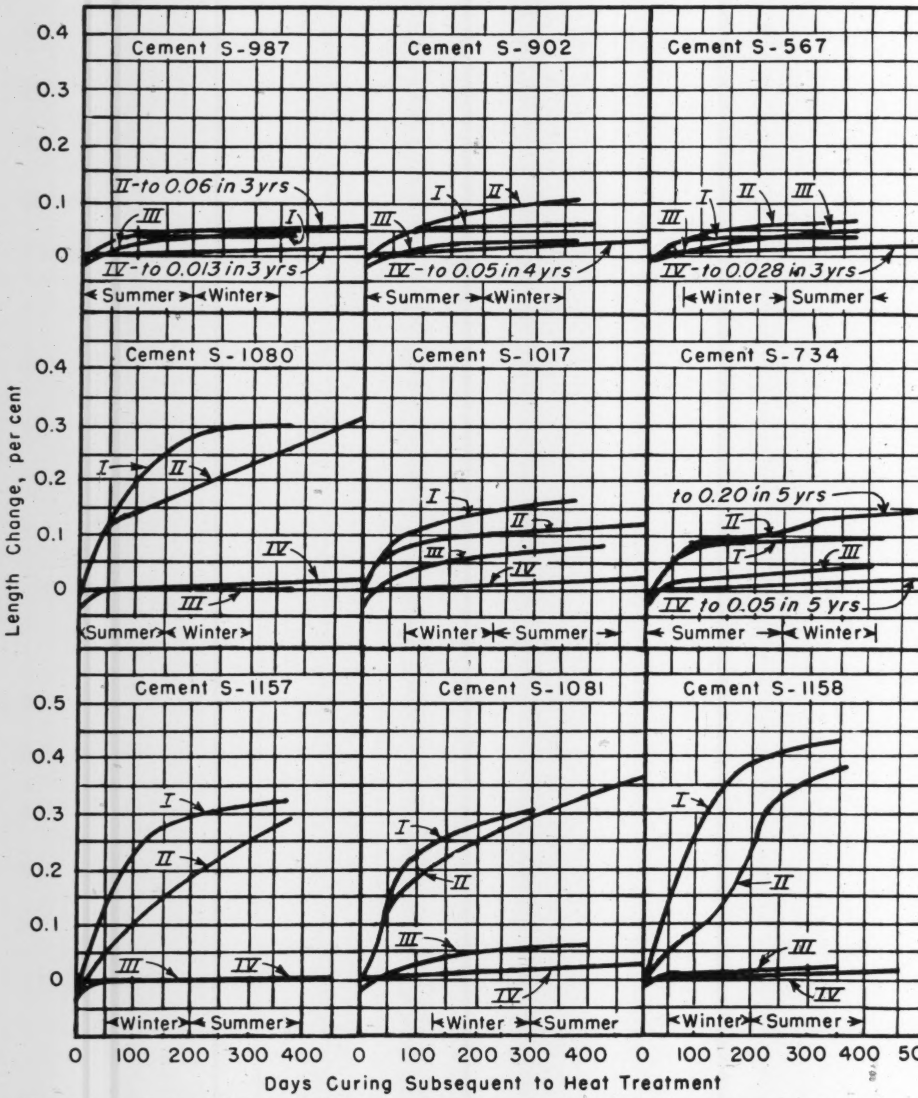


FIG. 5.—A Group of Curves for Tests of Various Type II Portland Cements, Showing Lo Medium, and High Expansion Tendencies.

The chemical analysis, compound composition and specific surface of the cements may be found in Table IV.
Curve I—28 days standard cure, 130 F heat treatment, standard temperature water thereafter (adopted exposure
Curve II—28 days standard cure, 130 F heat treatment, outdoor exposure thereafter.
Curve III—7 days standard cure, 21 days air cure, alternate 70 F water and 130 F air thereafter.
Curve IV—7 days standard cure, outdoor weather exposure thereafter.

9. The resistance to freezing and thawing decreased after heat treatment
130 F. This is believed to have affect
expansion in outdoor storage where spe
mens were subjected to freezing ar
thawing during the winter months.

Figure 2 shows groups of curves o

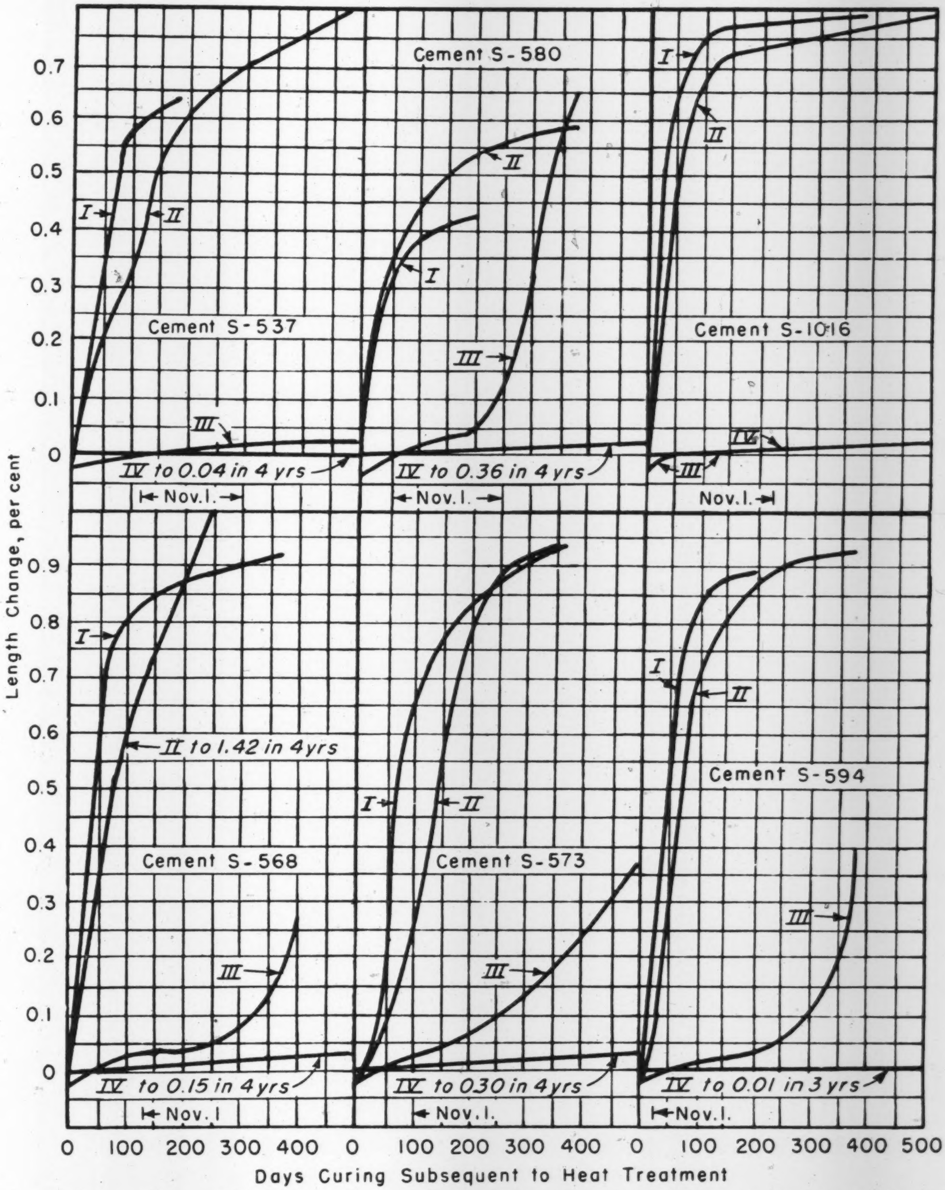


FIG. 6.—A Group of Curves for Tests of Various Type III Portland Cements Showing the Range of Expansion Tendencies.

The chemical analysis, compound composition and specific surface of the cements may be found in Table IV.
Curve I—28 days standard cure, 130 F heat treatment, standard temperature water thereafter (adopted exposure).
Curve II—28 days standard cure, 130 F heat treatment, outdoor exposure thereafter.
Curve III—7 days standard cure, 21 days air cure, alternate 70 F water and 130 F air thereafter.
Curve IV—7 days standard cure, outdoor weather exposure thereafter.

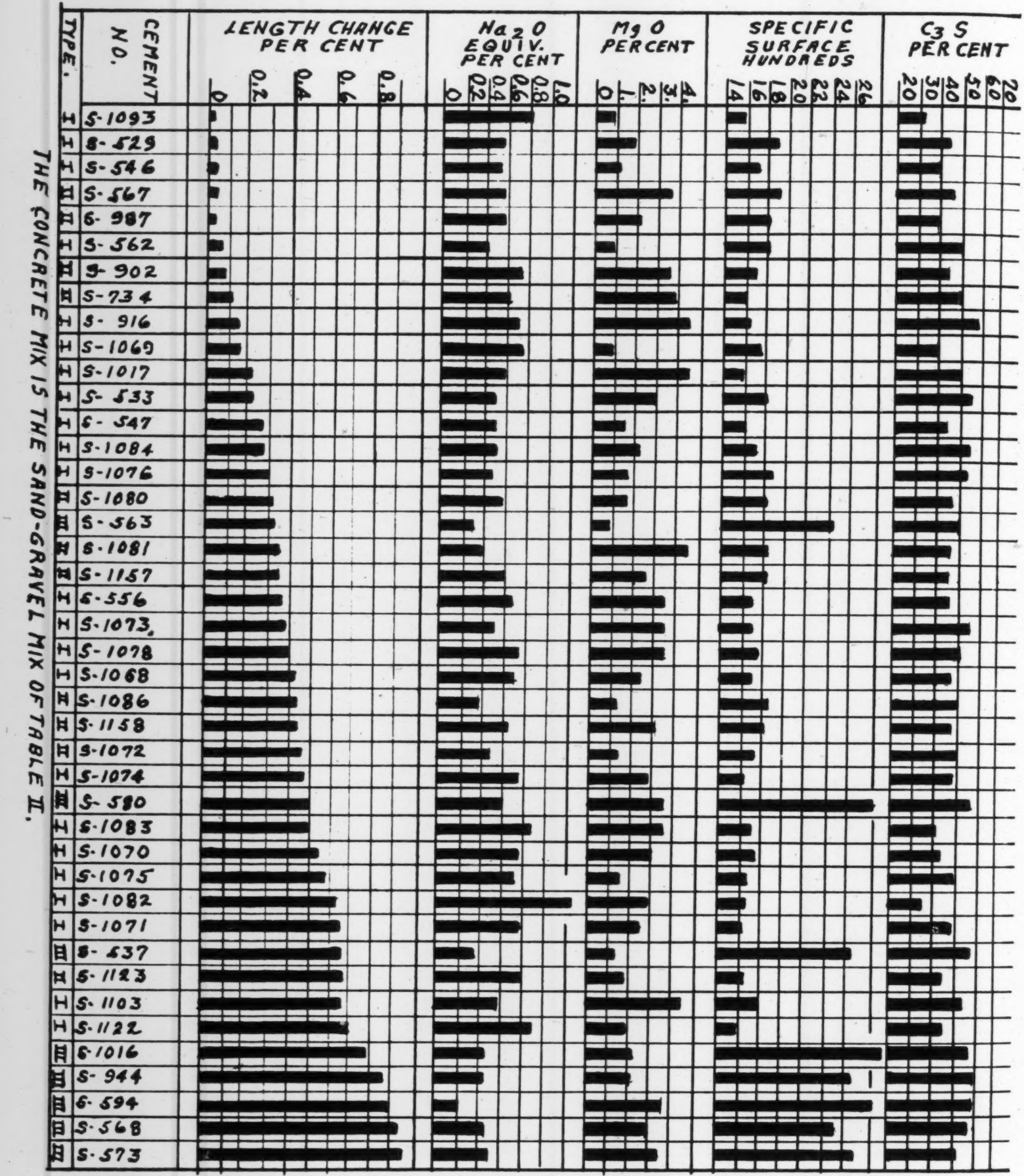
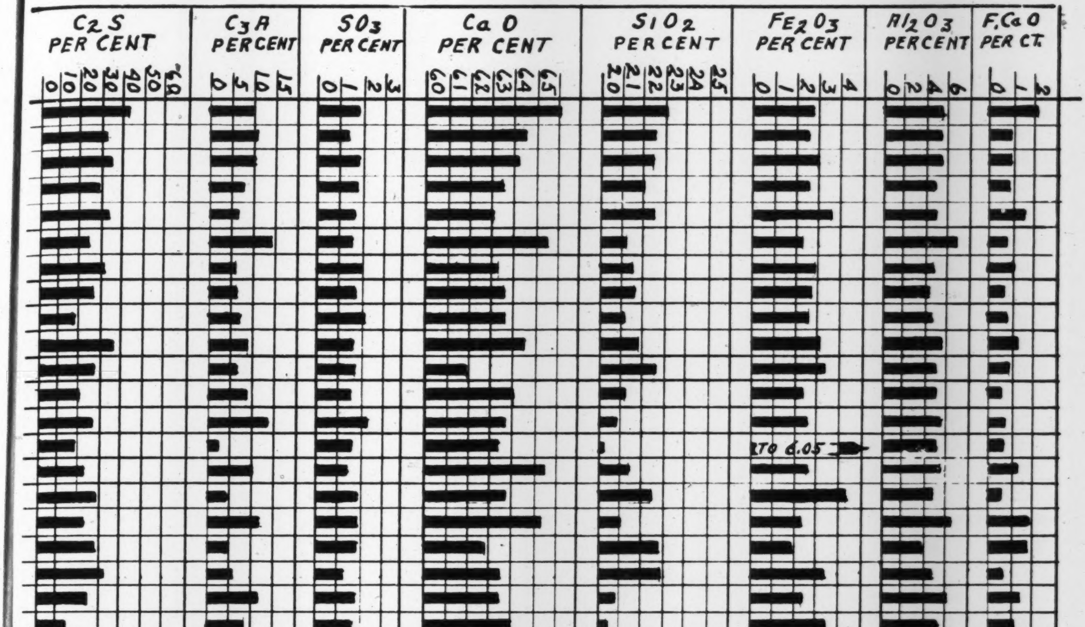


FIG. 7.—Bar Chart Showing Abnormal Expansion of Sand-Gravel Concretes Under Conditions of Exposure

The concretes contain Kaw River sand-gravel aggregate



o. I, the Standard Test Procedure Adopted, and Its Relation to the Cement Compounds, Oxides, and Fineness
d 42 portland cements including types I, II, and III.

tained on types I and III cements under a number of the exposures listed. Exposure developments not shown were of little interest to this investigation. Figure 3 shows the effect of length of time of curing before heat treatment and the temperature of heat treatment.

Standard Test Procedure:

Having the information gained from the investigations mentioned, a standard test procedure was adopted for further study of the expansion and a search for means to prevent its development was initiated. The standard test was essentially the same as exposure 10 of the list of exposures explored. The standard test procedure adopted is outlined in Appendix I and has been designated as exposure I.

Other Test Procedures:

Other test procedures retained and used for obtaining additional information and correlation are given numbers as follows for reference purposes: Exposure II, exposure III and exposure IV. These exposures are essentially as follows:

Exposure II consisted of a schedule the same as for exposure I through II*d*, after which the specimens were given seven days standard-temperature water storage, then removed to outdoor storage, bedded in earth with troweled surface flush with ground surface. Readings are taken in the spring and fall of each year to observe growth if any.

Exposure III is the exposure and cycle used by C. H. Scholer (3) in his wetting and drying—heating and cooling test, as described for exposure 12 in the listing of exposures used in exploratory work.

Exposure IV is continuous outdoor storage as given for exposure 20 in the list of exploratory exposures after a preliminary curing for seven days in a standard temperature fog room.

Standard Test Procedure Used to Test Cements:

Having adopted a standard test procedure with auxiliary tests, many cements have been tested with the reactive sand-gravel aggregate, including types I, IA, II, IIA, and III from many mills. Also, commercial portland-pozzolanic cements and blends of portland cement with many pozzolans were tested. Due to space limitations, no data or curves for types IA, IIA or IIIA cements are given, but the abnormal expansions of concretes made with these types were substantially reduced.

Figure 4 shows the expansions obtained under exposures I to IV inclusive, of a group of type I portland cements. The Roman numerals with arrows pointing to curves indicate the exposure.

Figure 5 shows the expansions obtained under the same exposures for a group of type II portland cements.

Figure 6 shows the expansions obtained under the same exposures for a group of type III portland cements.

Figure 7 is a bar chart showing the expansion obtained on 42 portland cements from 23 mills. There are some repeat tests from some mills from samples obtained over one year apart.

Search for a Preventive or Inhibitor:

When the information given by Figs. 4, 5, 6, and 7 is studied, it may be seen that some of both types I and II cements show low expansive tendencies, but it is not possible to determine the oxide analysis or compound composition that will insure low expansion. There seems a strong possibility that the high expansion is related in some way to the potential calcium hydroxide release from hydration of the cement and the rate of this release.

The high-early-strength cements all show high abnormal expansion. The potential calcium hydroxide release of these cements is high and, due to high fineness, the rate of release may be high. Many type I cements may have high potential lime release, but the rate of release may vary because of variable fineness. Little is known about the quantity and rate of release of calcium hydroxide during the hydration of portland cements or of the activities of this constituent after release. It is known that some of it carbonates, after which it is relatively inert, but carbonation may be largely confined to the surface.

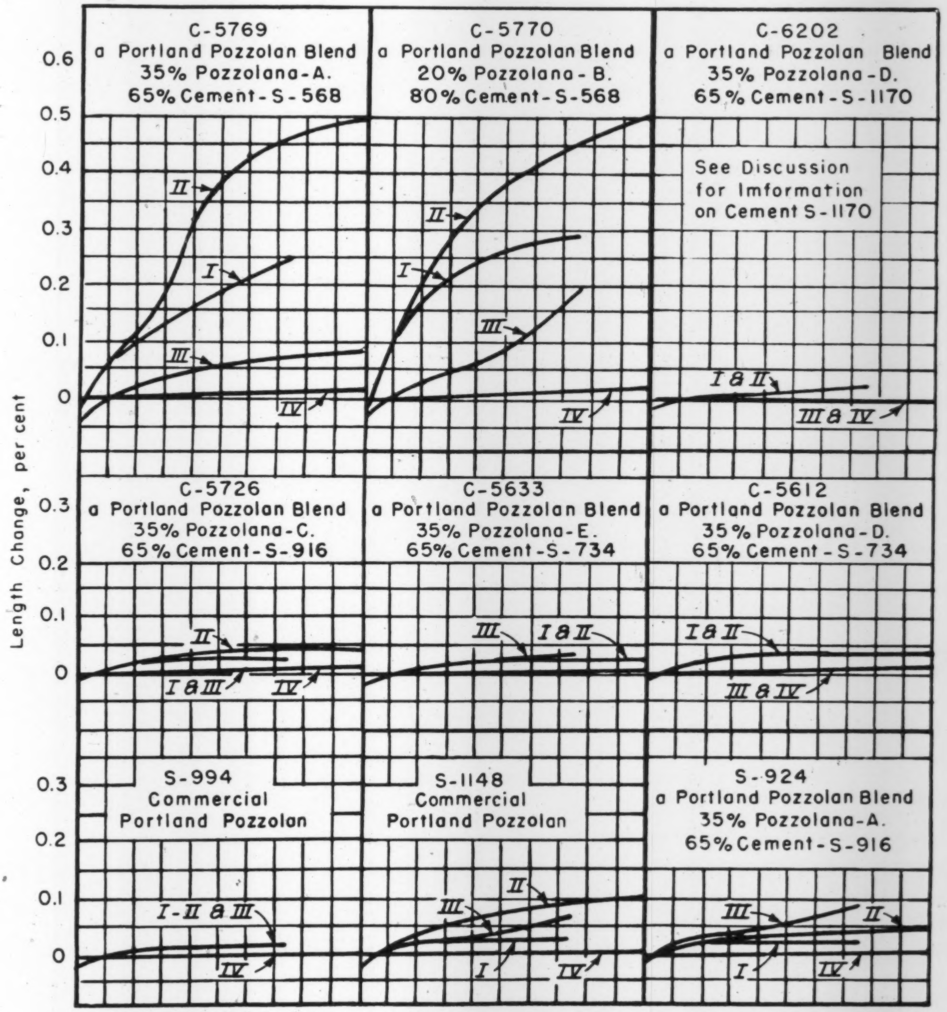


FIG. 8.—A Group of Curves for Tests of Concretes Made with Kaw River Sand Gravel and Various Portland Pozzolana Cements.

The base cements for the upper three sets of curves were those showing nearly 1.0 per cent expansion under the adopted exposure 1.

Curve I—28 days standard cure, 130 F heat treatment, standard temperature water thereafter (adopted exposure).
Curve II—28 days standard cure, 130 F heat treatment, outdoor exposure thereafter.
Curve III—7 days standard cure, 21 days air cure, alternate 70 F water and 130 F air thereafter.
Curve IV—7 days standard cure, outdoor weather exposure thereafter.

If the calcium hydroxide released by hydration of the cement is responsible for the abnormal expansion, a practical means for converting it to the relatively inert calcium carbonate or calcium silicate may prevent or inhibit the abnormal expansion if such means can be found. There seemed to be no practical way to carbonate quickly the calcium hydroxide released, but pozzolanic materials are known to react with calcium hydroxide to form calcium silicate and to develop a cementing action similar to portland cement. It is quite practical to blend such a material with portland cement and for the pozzolanic action to develop sufficient strength that very little loss in strength development of the cement will result, especially at later ages.

To obtain information on the possibilities in this direction, a number of commercial portland pozzolan cements and portland-pozzolan blends were used as cement with the sand-gravel aggregate and subjected to exposures I, II, III, and IV. The curves of Fig. 8 show the expansions obtained with a number of such cements and blends.

The curves for concretes C-5769 and C-5770 show quite high abnormal expansion, but the base cement used for these tests was cement S-568, and it may be noted on Fig. 3 that this cement showed extremely high abnormal expansion, and the presence of the pozzolanic material has reduced it greatly. All other blends and portland-pozzolan cements in this group show very low expansive tendencies. Tests of many other blends have been made with similar results, but the results of these tests are not included in this paper.

Some pozzolans are more effective than others as may be expected, due to variable pozzolanic activity.

The chemical properties and fineness of the various cements and pozzolans included in Figs. 4, 5, 6, and 8 may be observed in Tables IV and V.

DISCUSSION

Studies of the results of the tests dealt with in this paper and many others indicate that abnormal expansion cannot be definitely related to any one cement constituent. To the author, it appears to be affected by the following, in order of their importance: (1) the quantity and rate of release of calcium hydroxide during the hydration of the cement; (2) the alkali content of the cement.

Additional factors which affect development of abnormal expansion because of their effect on item 1 above are the fineness to which the cement is ground and the compound composition of the cement. There seems to be a strong probability that the alkali acts much in the rôle of a catalyst.

The results of the test on concrete C-6202, shown in Fig. 8, is of considerable interest. Cement S-1170 is a type III portland cement which, when used in mortar bars with the Kaw River aggregate and aggregates from many other sources in the area north of Oklahoma and New Mexico, shows expansions under exposure I from 0.60 to 1.1 per cent. In the test indicated, the presence of the pozzolanic material appears to have prevented abnormal expansion development. This case of effective prevention is presented in this paper. Many other tests have been made with similar results but are not included here in the interest of brevity.

In none of the blends included in this paper was there sufficient substitution to lower the strength of the cement below type I requirements.

To the author, the nature of the action is still obscure and he can give no theory as a possible explanation. So far as the author knows, no deleterious action on concrete has been attributed to the presence of calcium hydroxide in concrete other than that its solubility may result in its being leached out by soft water percolation, causing loss in concrete strength.

action and with that knowledge improve the durability of portland cement concrete.

TABLE IV.—CHEMICAL ANALYSIS (PER CENT) AND FINENESS OF CEMENTS.

	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	F·CaO	Na_2O	K_2O	Na Eq	C_3S	C_2S	C_3A	Specific Surface
Type I														
S-1069	22.74	64.40	5.40	3.10	0.75	1.58	1.16	0.53	0.30	0.727	39.0	36.0	9.0	1760
S-1084	20.50	63.20	4.87	6.05	2.07	1.60	0.64	0.48	0.05	0.51	52.5	19.5	2.5	1700
S-916	21.20	63.70	4.30	2.60	4.37	2.06	0.78	0.23	0.65	0.65	56.0	18.5	7.0	1650
S-1068	20.98	64.10	6.40	2.64	2.36	1.82	0.64	0.51	0.23	0.66	47.0	25.0	12.5	1700
S-533	21.16	64.00	5.32	3.22	2.87	1.50	0.48	0.19	0.25	0.35	54.0	20.2	8.7	1800
S-547	20.82	63.70	6.71	2.61	1.37	2.11	0.72	0.20	0.42	0.48	42.8	27.5	13.5	1600
S-1071	20.74	64.60	6.30	2.62	2.37	1.57	1.57	0.57	0.33	0.78	48.5	23.0	12.0	1610
S-1103	21.88	63.35	4.55	2.55	4.44	1.57	0.89	0.12	0.68	0.56	53.0	22.6	7.7	1804
S-1122	21.06	63.90	5.70	2.86	1.70	2.01	1.51	0.73	0.22	0.87	45.5	26.5	10.5	2147
S-734	22.44	63.60	4.15	2.69	3.74	1.66	0.63	0.20	0.60	0.59	49.6	27.1	6.5	1580
Type II														
S-987	22.46	63.00	4.80	3.60	2.06	1.61	1.47	...	...	...	39.6	33.0	6.6	1800
S-902	22.48	63.15	4.33	2.87	3.41	1.87	1.00	0.17	0.76	0.67	43.6	31.7	6.7	1688
S-567	22.06	63.40	4.69	2.61	3.55	1.74	0.90	0.20	0.57	0.58	46.4	28.4	8.0	1920
S-1080	22.26	63.70	4.45	4.23	1.74	1.70	0.52	0.42	0.21	0.56	46.5	29.0	4.5	1800
S-1017	22.40	61.90	4.48	3.22	4.35	1.66	0.80	0.17	0.58	0.55	39.1	32.7	6.4	1960
S-734	22.44	63.60	4.15	2.69	3.74	1.66	0.63	0.20	0.60	0.60	49.6	27.1	6.5	1580
S-1157	22.88	63.36	4.68	3.28	2.63	1.20	0.58	0.34	0.37	0.58	44.5	32.0	6.5	1840
S-1081	22.86	62.75	3.88	1.90	4.45	1.80	1.74	0.36	0.19	0.48	36.0	38.5	7.0	1850
S-1158	22.14	62.95	4.72	3.22	3.01	1.51	0.81	0.35	0.41	0.62	47.0	28.0	7.0	1850
Type III														
S-537	20.88	65.20	5.15	2.91	1.14	2.32	1.20	0.17	0.24	0.33	56.7	17.3	8.5	2640
S-580	21.16	63.75	4.03	2.69	3.56	2.05	2.52	0.21	0.59	0.60	56.8	17.8	6.2	2820
S-1016	19.94	64.20	5.33	3.43	2.12	2.31	1.23	0.24	0.33	0.45	57.0	14.5	8.5	2990
S-568	20.04	64.50	5.67	2.61	2.83	2.20	1.50	0.25	0.32	0.46	56.9	14.8	10.6	2520
S-573	20.40	63.30	6.29	2.15	3.33	2.24	1.02	0.14	0.57	0.52	51.3	19.8	13.1	2690
S-594	21.42	63.60	5.06	2.47	3.56	2.08	0.90	0.13	0.10	0.20	48.5	24.9	9.2	2820
S-1170	20.52	63.90	5.52	3.38	1.89	2.45	0.56	0.28	0.35	0.51	55.0	17.5	9.0	2580
Portland Pozzolanas														
S-994	28.28	59.10	4.46	2.72	1.25	1.32	0.56	0.52	0.32	0.73	...	...	...	...
S-1148	41.56	43.50	7.08	2.46	3.28	1.26	0.41	0.10	0.48	0.42	...	...	...	...

TABLE V.—CHEMICAL ANALYSIS (PER CENT) AND FINENESS OF POZZOLANAS.

Designation	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	Na Eq	A.P.[a]
A	85.28	0.80	10.19	1.41	0.19	...	0.04	0.92	0.645	6280
B	72.18	1.50	16.17	4.37	1.12	...	1.16	2.36	2.71	...
C	66.72	6.75	8.01	6.25	2.88	...	0.87	1.59	1.91	13 780
D	80.80	0.55	11.64	2.08	0.44	...	0.58	1.26	1.40	8450
E	47.33	...	19.46	18.70	1.35	2.61	...	...	...	4003

[a] Determined by Blaine Air Permeability Method.

The developments observed during the exploration described are given here for the information of others with the hope that some with better investigational facilities may determine the nature of the

CONCLUSIONS

An abnormal expansion of portland-cement concrete which may be a factor in the unsatisfactory performance of portland-cement concrete in structures has been studied and some of the conditions under which it develops have been found.

The conditions favorable to development of the abnormal expansion are not outside the range of natural exposure.

The nature of the action producing the abnormal expansion has not been determined.

The magnitude of the expansion developing under favorable conditions is far greater than can be attributed to temperature and moisture variations or difference in the temperature coefficient of volume change of aggregates.

The development of the abnormal expansion in the concrete can be prevented or greatly decreased if a suitable pozzolanic material is incorporated in the concrete mixture in the proper amount, either as a blend with the portland cement or as an addition to the concrete mixture.

Limitation of alkali content in the cement within a practical range will not insure immunity from the expansion, for abnormal expansion has been caused to develop to a high degree in concrete made with portland cement as low in alkali as can be commercially produced.

Further study of this phenomenon is needed with facilities not now available to the author, to learn, if possible, the nature of the action causing the expansion.

REFERENCES

(1) T. E. Stanton, "Studies to Develop an Accelerated Test Procedure for the Detection of Adversely Reactive Cement-Aggregate Combinations," *Proceedings*, Am. Soc. Testing Mats., Vol. 43 pp. 875–904 (1943).

(2) U. S. Bureau of Reclamation, Progress Report "Alkalies in Cement and Their Effect on Aggregates and Concretes," *Laboratory Report No. Ce 40*, July 1, 1942.

(3) C. H. Scholer, "A Wetting and Drying Test for Predicting Cement-Aggregate Reaction," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 942 (1949).

APPENDIX I

EXPOSURE I

I *Preliminary Curing and Measurements:*

(*a*) Cure in mold in fog room at standard temperature for 20 to 24 hr.

(*b*) Remove from mold, read length and fundamental vibration frequency by sonic method for Young's Modulus of Elasticity at standard temperature.

(*c*) Place in water storage at standard temperature for 20 to 24 hr. Make readings as given for *b* using extra care for the length reading since this reading will be used as the base length, then return specimens to water storage until specimens are 28 days age.

II *Subsequent Treatment:*

(*a*) Place in a controlled temperature water bath at 130 F for seven days.

(*b*) Cool to standard temperature in water allowing specimens to remain in standard-temperature water storage for 20 to 24 hr.

(*c*) Place in 130 F drying oven for seven days.

(*d*) Cool to standard temperature dry for 20 to 24 hr.

(*e*) Place in standard-temperature water storage indefinitely, pending developments.

III *Measurements and Tests:*

Read length and fundamental vibration frequency by sonic method for Young's Modulus of Elasticity with beams at standard temperature, except where otherwise noted as follows:

(*a*) Upon removal from molds at standard temperature fog storage.

(*b*) After 20 to 24 hr in water at standard temperature, a careful reading for base length.

(*c*) At 28-day age upon removal from standard-temperature water storage to transfer to 130 F water storage.

(*d*) Upon removal from 130 F water storage after seven days at 130 F in water with specimens approximately at the 130 F storage temperature.

(*e*) After cooled to 70 F by storage for 20 to 24 hr in water at standard temperature.

(*f*) After seven days in drying oven at 130 F while still at approximately the 130 F oven temperature.

(*g*) After cooled dry in a desiccator to standard temperature for 20 to 24 hr.

(*h*) After 20 to 24 hr in standard-temperature water bath.

(*i*) After 3 days in standard-temperature water bath.

(*j*) After 7 days in standard-temperature water bath.

(*k*) After 28-day intervals during period of storage in standard-temperature water bath.

DISCUSSION

Mr. Lal C. Verman.[1]—In 1940 Mr. Khan and I published a study[2] of the effect of pozzolanic mixtures with portland cement on the development of its strength. The theory which we at that time felt was responsible for the beneficial effect of pozzolana on the strength of cement was that pozzolana tended to react with the free lime resulting from the normal setting reactions in cement. Although we had no definite evidence of the accuracy of this theory, the experiments described were originally conceived on the basis of such a hypothesis. It was demonstrated that the strength of cement mixtures with the overburned surkhi (powdered building brick) may reach 125 to 150 per cent of the neat cement. The Figs. 9 and 10 give the results with two different cements for various mixture ratios.

Mr. William Lerch[3] (*by letter*).—There is an urgent need for more precise laboratory tests for aggregates and cement aggregate combinations to determine their potentialities for producing abnormal expansion in concrete. Mr. Conrow has described a test that does show considerable promise. The studies described in the paper are confined, in large part, to tests made with one aggregate, a sand-gravel aggregate from the Kaw River. The aggregate has a poor service record in concrete pavements and structures.

It would be desirable to obtain information as to the nature of the reactions that cause the abnormal expansion. Mr. Conrow has shown that expansion can be prevented or substantially decreased by the use of a suitable pozzolanic material. From this observation it might be concluded that the reaction of the pozzolan with the alkalies and calcium hydroxide in the cement paste was beneficial. However, it should be recalled that C. H. Scholer and W. E. Gibson[4] have shown, by a different method of test, that the abnormal expansion can be prevented by additions of limestone coarse aggregate. Likewise, concrete pavements and structures containing Kaw River sand-gravel aggregate with limestone additions have a good service record.

It would be of interest to have information on the performance of a considerable number of different aggregates in the test proposed by Mr. Conrow and to relate the expansions obtained with the actual field performance of the aggregates. The relationship between the results obtained in a laboratory test with performance records provides the best method for evaluating the test. Subcommittee II-b on Chemical Reactions of Aggregates in Concrete of ASTM Committee C-9 on Concrete and Concrete Aggregates has a cooperative series of tests under way to determine the reproducibility of the test in different laboratories. This series of tests includes the use of three different aggregates in combination with each of three different cements. The results of

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[1] Director, Indian Standards Institution, Delhi, India.

[2] C. A. R. Khan and Lal C. Verman, "Cement-Surkhi Mortar", *Indian and Eastern Engineer*, Vol. 86, June, 1940, pp. 613–615.

[3] Administrative Assistant, Portland Cement Assn., Chicago, Ill.

[4] "Effect of Various Coarse Aggregates upon the Cement-Aggregate Reaction," *Journal*, Am. Concrete Inst., Vol. 19, No. 10, June, 1948; *Proceedings*, Vol. 44, p. 1009 (1948).

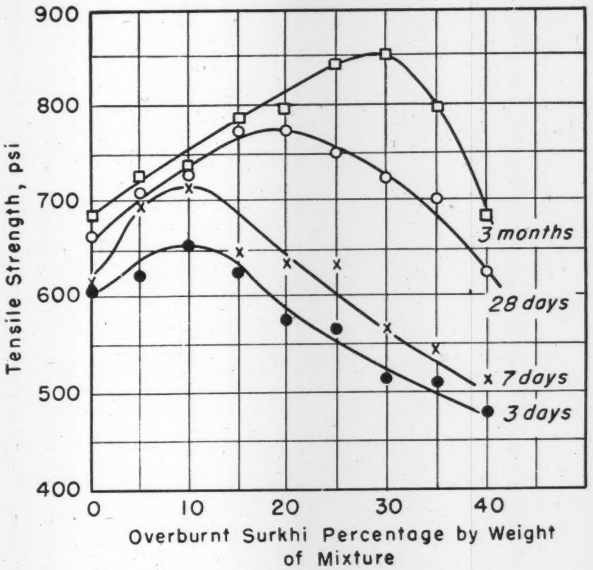

FIG. 9.—Effect of Overburned Surkhi on Tensile Strength of Cement A as a Function of Surkhi Percentage.

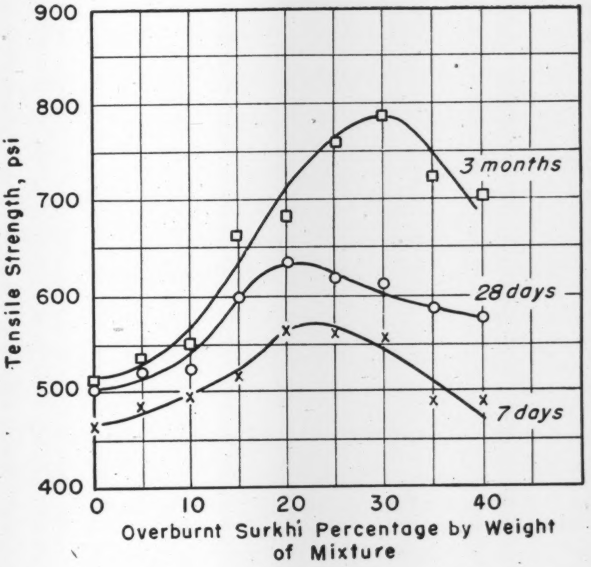

FIG. 10.—Effect of Overburned Surkhi on Tensile Strength of Cement B as a Function of Surkhi Percentage.

these tests will supplement the data reported by Mr. Conrow. The test is of sufficient interest to warrant further extensive study.

MR. BRYANT MATHER[5] (*by letter*).—Mr. Conrow should be especially commended for his restraint when he writes "the nature of the action producing the abnormal expansion has not been determined." Too often the tendency to jump to a conclusion or the pressures that are brought to bear to arrive at one, cause phenomena to be prematurely placed in existing categories.

Mr. Conrow implies that the phenomena observed are limited, at least as far as is at present known, to concrete made with certain natural siliceous aggregates from the Central Great Plains region of the United States. He concludes that there is a strong possibility that the abnormal expansion is related in some way to the amount and rate of development of calcium hydroxide during cement hydration, and that the alkalies (soda and potassa) act as catalysts. He finds that the abnormal expansion can be prevented or much decreased by the use of a proper amount of a suitable pozzolan. He seems to suggest that possibly the principal function of the pozzolan is the obvious one of using up the calcium hydroxide. Since he states that it has been quite definitely demonstrated that the abnormal expansion is not consistently related to the alkali content of the cement, he appears to imply that the phenomena involved are significantly different from what now might be called the "classical" alkali-aggregate reaction.

Mr. Conrow suggests that if the calcium hydroxide is responsible for the expansion, the carbonation of the hydroxide might be expected to prevent or inhibit the expansion. In this connection reference may be made to the experiments by Gaskin[6] who investigated the possibility of preventing alkali-aggregate reaction by carbonating the sodium and potassium hydroxides by exposure to carbon dioxide. His results led him to conclude that the presence of an excess of carbon dioxide prevented the expansion, apparently by the formation of relatively impermeable protective shells of calcite around particles of reactive aggregate.

It has been observed in this laboratory that all samples of concrete or mortar that have undergone alkali-aggregate reaction and that have been subjected to microscope examination are characterized by materially reduced quantities of crystalline calcium hydroxide. The presumption that the alkali-aggregate reactions themselves are responsible for this apparent consumption of calcium hydroxide is therefore suggested. It has been indicated that the pozzolanic reaction which consumes calcium hydroxide prevents or inhibits the deleterious effects of the alkali-aggregate reaction. If it may be further assumed that the presence of crystalline calcium hydroxide is necessary to the progress of the alkali-aggregate reaction, then the interesting possibility, which Mr. Conrow has mentioned, is suggested: that the mere consumption of calcium hydroxide by reaction with a pozzolan is sufficient to explain the beneficial effects of pozzolans in preventing abnormal expansion.

Mr. Conrow indicates that additional study is needed. The writer would like to propose several items, the study of which might be expected to shed light on these and related problems:

1. Thorough petrographic examination of the aggregates that are involved, with particular reference to differences between them and apparently similar materials that do not behave similarly

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[5] Engineer, Concrete Research Division, Waterways Experiment Station, Corps of Engineers, U. S. Army, Jackson, Miss.

[6] A. J. Gaskin, "The Effect of Carbon Dioxide—Studies in Cement-Aggregate Reaction, No. VI," Council for Scientific and Industrial Research, *Bulletin No. 229*, pp. 78–84, Melbourne, Australia (1947).

and to differences between the aggregates before and after they have been used in specimens that have undergone abnormal expansion.

2. Microscopic examination of the concrete at various stages in the development of the expansion to determine if detectable changes occur progressively in the aggregate particles, the hydration products of the cement, or in the cement-aggregate texture.

3. Subjection of other cement-aggregate combinations to the test exposure to determine if similar results may be obtained.

MR. A. D. CONROW (*author's closure*).—The writer appreciates the discussions of this paper by Messrs. Verman, Lerch, and Mather. The curves submitted by Mr. Verman are interesting. In a number of cases the writer has found the strength development in flexure of 35/65 blends of pozzolan and portland cement to be higher than that development by the base portland cement at the age of one year. Developments of higher compression strength of blends containing as high as 35 per cent pozzolan are not so frequently observed.

Mr. Lerch observes that the tests are confined largely to one aggregate. This is true in connection with this paper, which was presented to outline the explorations made during development of a testing method that could be used for further study. However, the aggregate used can be considered representative of much to be found in the Central Plains Region of the United States. He also mentions the tests by C. H. Scholer and W. E. Gibson which indicate that another method can be used to inhibit or decrease the abnormal expansion. It may be pointed out that this method does not lend itself for use in developing a structural cement which can be used with aggregates of the character involved in these tests with assurance that abnormal expansion will not develop.

This paper limited its field essentially to development of a method of test in order to confine it to a reasonable volume.

Tests have been made, or are under way, on a considerable number of aggregates, and the writer has specimens from over 100 concretes showing a wide range of expansion under the method developed that have been exposed to natural weathering in an attempt to learn whether there is a correlation in expansion under that condition and that observed under the test method. It requires 5 to 8 yr in natural exposure for the abnormal expansion to develop.

Some of the specimens have now been exposed for over 5 yr and some showing high expansion under the test method developed are beginning to show quite high expansion under natural exposure. Insufficient data has accumulated in this field of exploration to state with assurance that high expansion developing under the test method indicates a predominating probability that high expansion will develop under natural exposure. Development of abnormal expansion under the test method may serve as a warning.

Mr. Mather mentions carbonation as a possible preventative of abnormal expansion and calls attention to the work of Gaskin.

The writer has tried some experiments with carbonation and found that if concrete made with the aggregate used in these exploratory tests was carbonated by thorough saturation with a strong sodium carbonate solution, abnormal expansion did not develop. Carbonation by this means is not practical in construction.

Mr. Mather suggests three items for further study. The writer has now accumulated considerable data on other cement-aggregate combinations but is not equipped to make petrographic or microscopic studies. It is hoped that information obtained from further studies can be given in future papers.

CRACKING IN MASONRY CAUSED BY EXPANSION OF MORTAR*

By J. W. McBurney[1]

Synopsis

The effect of free magnesium oxide (MgO) in causing the expansion of hardened masonry mortars is discussed. From information available in the literature, from the results of length change measurements on brick piers laid with mortar containing excessive quantities of MgO, and from the examination of buildings, including laboratory tests of masonry materials, it is concluded that the delayed hydration of MgO can cause expansions of sufficient magnitude to produce severe cracking and structural damage in masonry. Some other causes of cracking are listed, and the probable origin of certain openings between units and mortar joints is considered. Recommendations for the prevention of trouble from expansive mortars are offered.

The cause of cracking in unit masonry is ascribed in most published reports to either structural and design features, including thermal expansion and contraction, or irreversible volume changes, usually shrinkage of mortar or units. The Seelye, Stevenson, and Value (**1**)[2] report, for example, lists foundation settlement, deflection of beams, overloading, expansion and contraction with temperature change, and various features of faulty design and construction as the causes of cracking. Palmer (**2**), on the other hand, presented data on the effects of wetting and drying and of temperature changes in causing volume change in brick and on mortar cast in metal molds. Davis and Troxell (**3**) measured length changes on brick piers laid with various mortars.

Numerous statements have appeared such as Scripture's (**4**) "Practically all authorities agree that the principal cause of leaky brickwork is mortar shrinkage, with ensuing shrinkage cracks." The correctness of these views may be questionable. The confusion appears to have arisen in part from misinterpretation of such data as those of Palmer (**2**), in part from mistaking openings between mortar and units for shrinkage cracks when in fact they result from the techniques of the mason, and in part from assuming that a crack is necessarily the result of shrinkage.

The present paper reports the results of studies, including laboratory examinations, of certain cases of cracking investigated by the National Bureau of Standards during the past several years. The examples presented are those in which the evidence indicates that the damage resulted from expansion which was caused by the delayed hydration of free magnesium oxide in the mortar. "Moisture expansion" of fired clay units, the effect of soluble sulfates on portland

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23-27, 1952.

[1] Technologist, National Bureau of Standards, Washington, D. C.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1247.

cement, and the behavior of certain highly vitrified clay bodies are not considered in this paper.

Review of Literature

The effect of delayed hydration of the free magnesium oxide (MgO) in normal dolomitic hydrated lime[3] in causing expansion and bulging of plaster is so well known that the ASA Sectional Committee A42 on Plastering, for example, in its 1946 Standard Specifications for Gypsum Plastering[4] barred the use of such limes for "white coat." This standard and its 1950 revision restricts lime to "special" finishing lime[5], which includes both high-calcium and pressure-hydrated dolomitic lime.[6] The history and theory of hydration of magnesia in dolomitic-hydrated limes and putties are presented in detail in a series of papers by Wells and his coworkers (**5**, **6**, **7**). These papers consider for the most part the effect on plaster of delayed hydration of MgO. Much of the data, however, is based upon tests of cement-lime mixes, and their application to masonry mortar is obvious.

The effect of free magnesium oxide (MgO) in causing expansions of portland cement was recognized by Campbell and White (**8**) as early as 1906. Modern specifications[7] for portland cement limit the MgO content to 5.0 per cent and also require an autoclave test[8] for soundness with a limit of 0.5 per cent for maximum expansion. Davis and Troxell (**3**) noted that a brick pier laid with a 1:1:3 portland cement–magnesium hydrated lime–sand mortar "was still expanding at a fairly rapid rate after 170 days, at which time its expansion amounted to 0.050 per cent." The piers in this series of experiments were exposed in air of 50 per cent relative humidity. The work of these authors was unusual in that they measured volume changes on masonry (brick) piers in addition to testing mortar bars cast in absorbent and nonabsorbent molds. They give as one of their conclusions: "The volumetric changes of a mortar bar cast in a nonabsorbent mold and stored in air is no criterion to the volumetric changes that may be expected to occur in the same kind of mortar when used as the joint material in brickwork." These investigators found that "brick piers in air expand during the first two or three months" and "after reaching their maximum expansion in air, the brick piers shrink continuously and quite uniformly until they regain their original length when 12 to 14 months old." The exceptions to this were the piers built with mortar containing magnesian (dolomitic) lime which continued to expand. These authors report, as usual, large shrinkages on mortar bars cast in nonabsorbent molds and cured in air. Pearson (**9**) had called attention to the variable results obtained in measuring volume changes of mortars. (See also the conclusions reported by Anderegg (**10**).) Palmer (**2**) also obtained shrinkage results from air drying of mortar specimens cast in nonabsorbent molds. Again, the exceptions were those mortars containing dolomitic hydrated lime. Withey and Wendt (**11**) noted that "dolomitic lime-cement mortars containing over 11 per cent of hydrate by weight of cement expanded unduly when continuously wet or when moist cured and tested in an autoclave."

The case described by Ortman (**12**), as far as is known to this author, is the only publicly reported example of masonry damage occurring in the United States where the trouble was ascribed to the use of mortars containing free MgO. This was the cracking of architectural terra cotta in the Telephone Building and other structures in San Francisco. Ortman stated "... it was discovered that the trouble existed only on buildings backed up with brick and mortar and where the mortar was compounded from approximately the above formula" (1:1:3 portland cement-high magnesian hydrated lime-sand by volume). Also "Simultaneous tests were conducted by engineers of this company (Gladding-McBean) in which piers 6 ft high and of exactly the same cross-section as those on the telephone building were erected, backed-up with brickwork in which different mortars were used, and kept wet over a long period of time. Those piers on which mortars of the same or closely similar composition to the above were used, failed in exactly the same manner, whereas those piers erected at the same time and given the same treatment, except that the mortar used in the backing was made of high-calcium lime putty, did not fail."

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[3] Standard Specifications for Normal Finishing Hydrated Lime (C 6 – 49), 1949 Book of ASTM Standards, Part 3, p. 159.

[4] Standard Specifications for Gypsum Plastering (Including Requirement for Lathing and Furring), ASA Designation A42.1, 1946. Am. Soc. Testing Mats., Am. Inst. of Architects, and American Standards Association.

[5] Standard Specifications for Special Finishing Hydrated Lime (C 206 – 49), 1949 Book of ASTM Standards, Part 3, p. 161.

[6] The "normal" and "special" classifications are both included in the ASTM Standard Specifications for Hydrated Lime for Masonry Purposes (C 207 – 49), 1949 Book of Standards, Part 3, p. 163.

[7] Standard Specifications for Portland Cement, (C 150 – 49), 1949 Book of ASTM Standards, Part 3, pp. 1–4.

[8] Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 – 49), 1949 Book of ASTM Standards, Part 3, pp. 35–37.

The English recognize "unsoundness of lime" as a cause of expansion of brickwork. The Bulletin by Bonnell and Pippard (13) contains two illustrations showing cracking of a brick wall and of a parapet wall "caused by unsound lime in mortar." According to these authors, "Unsoundness in lime is caused by the presence of unslaked particles of quicklime. Unless sufficient care is taken in slaking or hydrating quicklime, any over-burnt material present may still be unslaked when used in the building mortar and these unslaked particles will hydrate later when in the wall. This may have no serious effect if the mortar is very weak, but the increase in volume that accompanies slaking may produce serious effects when cement-lime mixes are used or when the expansion of a weak mortar is restrained by a strong pointing. Unsoundness is more likely to occur with limes slaked on the site than with commercially hydrated limes." Bonnell and Pippard did not identify the limes causing expansion.

On the other hand, the recent paper by Stutterheim, Webb, and Uranovsky (14) identifies their unsound lime as follows: "In the region (South Africa) where such failures have been observed, limes used in building are almost exclusively of the dolomitic and magnesian types." They consider unsoundness of lime as "causing 'popping' and 'bulging' and also a much more insidious type of trouble in which mortar expands in masonry joints, resulting in disruption of these joints and disfigurement of plaster. Such expansion generally manifests itself about six months after building and may continue for years." This paper concludes with the rather surprising statement: "The presence of unhydrated magnesia in a lime does not necessarily cause expansion, and no satisfactory correlation appears to have been established between unsoundness tests and the behavior of the material in practice." The second part of this conclusion appears to be based upon some references which recent developments have made rather questionable.

Observations and Measurements

The following two examples of damaging expansions of masonry caused by delayed hydration of magnesium oxide are taken from the files of the National Bureau of Standards.

Piers at National Bureau of Standards:

In September 1938, two piers 7 ft high by 3 ft wide by 8 in. thick were built in the Bureau's exposure test plot. Chicago common brick was used. Tests on samples

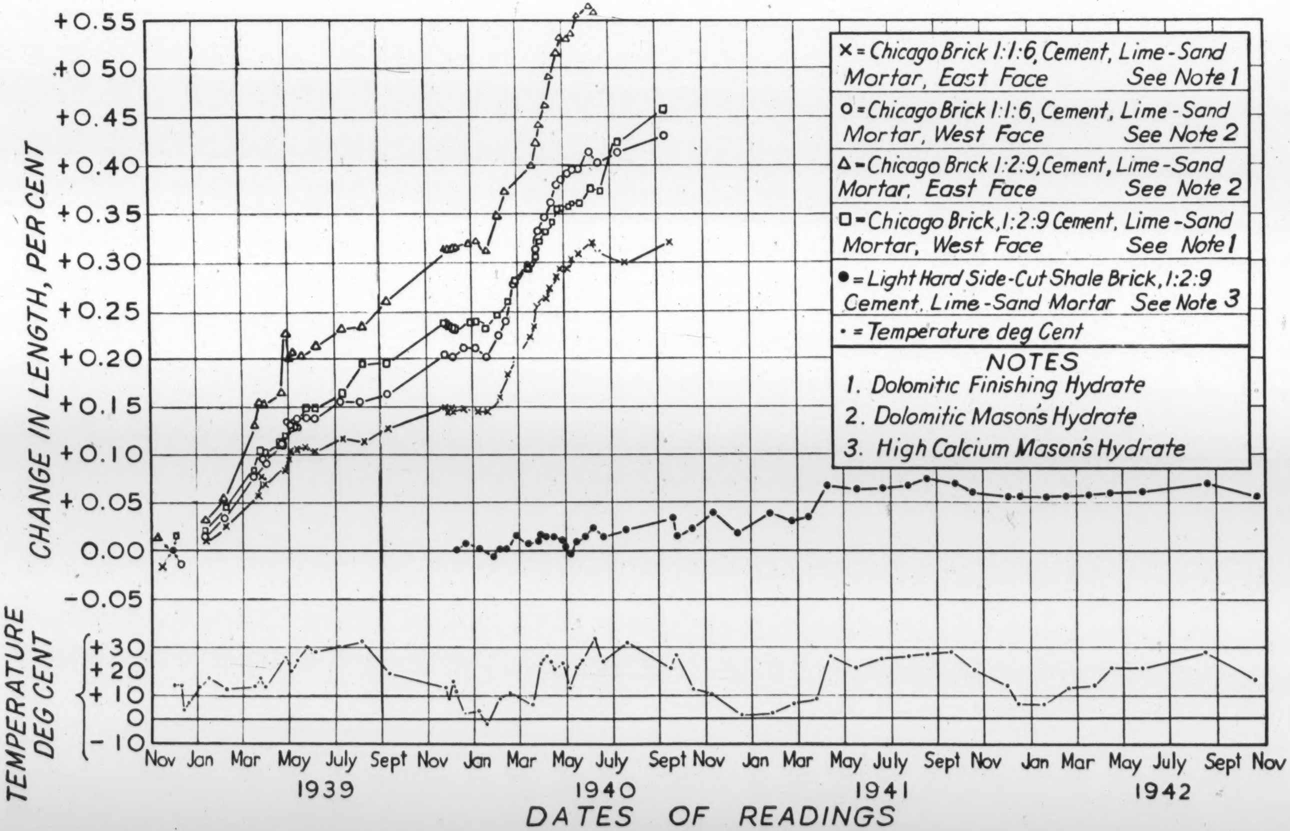

Fig. 1.—Change of Length with Time of Brick Piers Laid with Portland Cement - Dolomitic Hydrated Lime - Sand Mortars and with Cement - High Calcium Lime - Sand Mortar.

of these brick gave average water absorptions of 11.6 per cent by 24-hr cold absorption, 15.2 per cent by 5-hr boiling and an average saturation coefficient of 0.75. The compressive strength averaged 3500 psi. These results indicate compliance with the requirement for the top grade (SW) of the present ASTM Standard Specification for Building Brick Made From Clay or Shale (C 62 – 49).[9]

Chicago common brick characteristically contain lumps of burned lime (dolomite). These lumps hydrate rather quickly on exposure and under some conditions cause spalling of the brick surface. The bricks used in these piers had been exposed to the weather for 2 years before use, and hydration of the lime was probably completed.

TABLE I.—EARLY LENGTH CHANGES ON PIERS LAID WITH MORTARS CONTAINING DOLOMITIC LIME.

Composition of mortar		1:1:6		1:2:9	
Lime .... Symbols in Fig. 1		Finishing ✕	Masons ○	Masons △	Finishing □
Date	Temperature, deg Cent	Change in Length, per cent			
11-30-38	14	0.0000	0.0000	0.0000	0.0000
12- 7-38	14	+0.0012	+0.0020	+0.0041	+0.0060
12-13-38	4	−0.0002	0.0000	+0.0033	+0.0046
12-20-38	6	−0.0004	−0.0003	+0.0043	+0.0043
1- 3-39	14	+0.0104	+0.0108	+0.0204	+0.0158
1-11-39	17	+0.0130	+0.0170	+0.0281	+0.0206

The south wall was laid with a nominal 1:1:6 cement–lime–sand mortar by volume and the north wall with 1:2:9 mortar. The original intention was to have dolomitic finishing hydrated lime in the mortar used on one side of these walls and a high–calcium mason's lime in the other side. Through inadvertence, a dolomitic mason's hydrate was used instead of the high–calcium hydrate as intended. Analyses of mortar samples showed that both limes were dolomitic. Of the two limes used in these piers, one was not identified as to its actual manufacturer. The other was a well-known brand of finishing hydrate (type N)[3] produced in northwestern Ohio. Research Paper RP1917 (6) reports autoclave expansions on three separate samples of the "regularly hydrated dolomitic lime" produced by this manufacturer. The expansions on bars made of equal weights of portland cement and hydrated lime (approximately 1:2 by volume) ranged from a minimum of 12.9 to a maximum of 17.7 per cent. The calculated "unhydrated oxide" in those samples ranged from 26.2 to 29.9 per cent.[10]

Length changes with a Whittemore strain gage were measured at intervals beginning in November 1938. The last readings were made in September 1940. Figure 1 shows the gain in vertical length (20-in. gage) plotted against time. Early length changes (November 30, 1938 up to and through January 11, 1939) are given in Table I.

For comparison, corresponding readings are included for a pier built with a "light hard" shale brick and laid in 1:2:9 cement–high calcium hydrated lime–sand mortar by volume. The brick averaged 6000 psi in compressive strength, 11.6 per cent water absorption by 24-hr cold immersion, 13.6 per cent by 5-hr boiling, and had a saturation coefficient of 0.85. The lime was a brand of mason's high-calcium hydrated lime having an autoclave expansion of 0.18 per cent (6) when tested as a cement–lime mixture 1:1 by weight.

Figure 2 is a close-up of mortar joints as they appeared in the north wall (1:2:9 mortar containing dolomitic lime) in June 1948. The cracking in the body of the mortar was first noted in April 1939. This same pier had already expanded approximately 0.2 per cent at that time. Subsequent to the discontinuance of readings, a crack approximately $\frac{1}{4}$ in. in width and running the horizontal length of the pier formed about two-thirds up from the base on the east face. A somewhat smaller crack appeared about the same time at approximately the same location on the pier built with 1:1:6 mortar. The appearance and location of these large cracks much resembled those noted in the gate pier (Fig. 7) of the St. Joseph's School (see page 1237).

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[9] Standard Specifications for Building Brick (Solid Masonry Units made from Clay or Shale) (C 62 – 49), 1949 Book of ASTM Standards, Part 3, pp. 564–569.

[10] It should be pointed out that the producer of these limes is now equipped for pressure hydrating. The corresponding expansions reported in RP1917 for this producer's highly hydrated dolomitic lime (type S of C 206) ranged between 0.42 and 1.2 per cent with "calculated unhydrated oxides" of from 2.3 to 5.1 per cent.

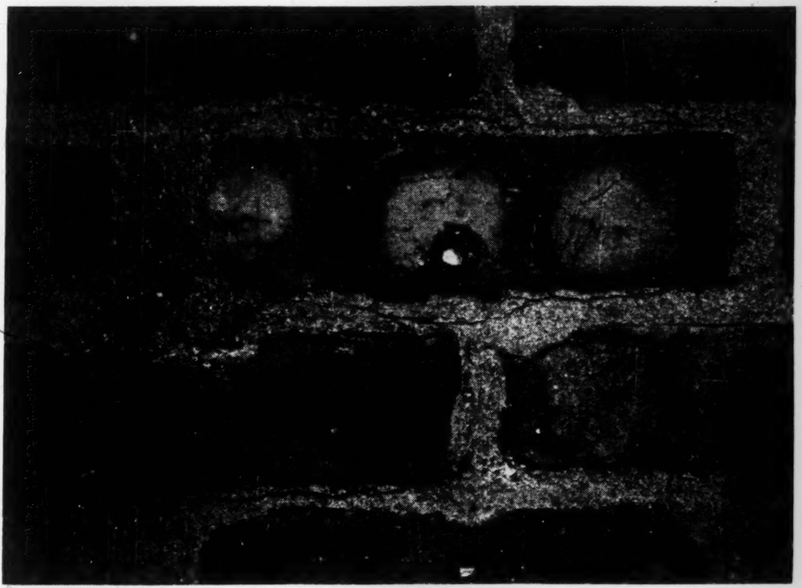

Fig. 2.—Close-up View of Mortar Joints in Pier Built with Chicago Common Brick Laid with 1:2:9 Cement-Dolomitic Hydrated Lime-Sand Mortar by Volume.

The pier was built in September 1938 and the photograph was taken in June 1948. Note cracks in mortar.

The openings between the bricks and mortar evident in Fig. 2 illustrate the type of "cracking" usually ascribed to mortar shrinkage. Scripture's paper (4), previously quoted presents an illustration of brickwork showing these cracks. Figures 3 and 4 of the present paper illustrate how openings, identical in appearance and location, are formed by the ordinary techniques of the brick mason. Figure 3 is a photograph taken a few seconds after a brick had been tapped down into the bed joint. Note the opening above the lip of extruded mortar and under the brick. Figure 4 shows a similar brick and mortar joint immediately after "cutting" with the trowel. "Cracking" is conspicuous above the bed joint and is also evident below. See also illustrations in Mallon's booklet (15). The explanation of this is that the bearing of a brick on a of bed joint is confined to the inner portion the joint. Mortar flows out from the joint without restraint or compaction (Fig. 3) as the brick is pressed down. Cutting of the joint accentuates these openings by tending to drag mortar out of the joint with "necking" of the joint at its plane of separation. That plastic mortar has tenacity is recognized by all who have worked with it. These "edge effects" are noted in the paper by J. C. Pearson (16)

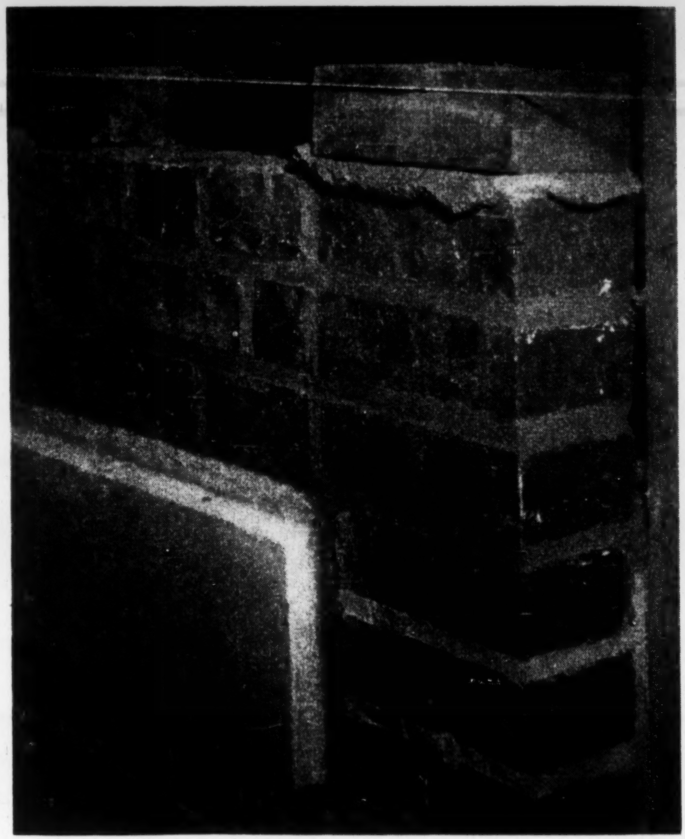

FIG. 3.—View of Brick Masonry During Construction Showing Extruded Lip of Mortar Forced Out by Tapping Brick into Bed Joint and the Horizontal Opening Between the Brick and the Bed Joint.

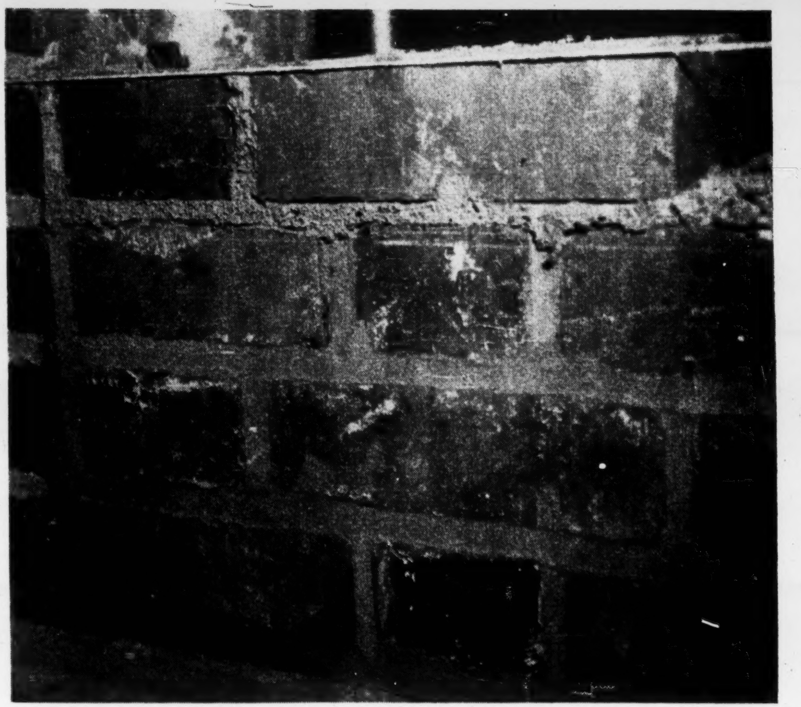

FIG. 4.—View of Same Masonry Illustrated in Fig. 3, Showing Openings Between Bricks and Bed Joint After "Cutting" of Mortar Joint.

and are further considered in the discussion of Pearson's paper by McBurney and Anderegg. See also paper by McBurney, Copeland, and Brink (17).

The size and extent of these openings appear to depend upon a number of factors. The consistency, water retentivity, and plasticity of the mortar and the initial rate of absorption of the unit are recognized as highly probable factors. Shrinkage of mortar is obviously not the explanation since (1) these openings appear instantly as the trowel passes over the joint and (2) the maximum width of the openings (0.1 in. in a 0.5-in. joint) greatly exceeds the greatest shrinkage of mortar ever reported. Furthermore, the experiments of Palmer and Parsons (18) with metal lugs inserted in mortar joints between bricks for the purpose of accentuating possible effects of shrinkage on bond between brick and mortar resulted in the following conclusions: "When the extent of bond is practically complete, the results do not indicate an appreciable weakening of the bond through shrinkage of the mortar during early hardening," and "There is no evidence that volume changes in mortar subsequent to hardening destroyed or weakened the bond either in vertical or horizontal joints when the extent of bond is good. When the extent of bond is poor, there is some indication that volume changes subsequent to hardening were destructive to the bond."

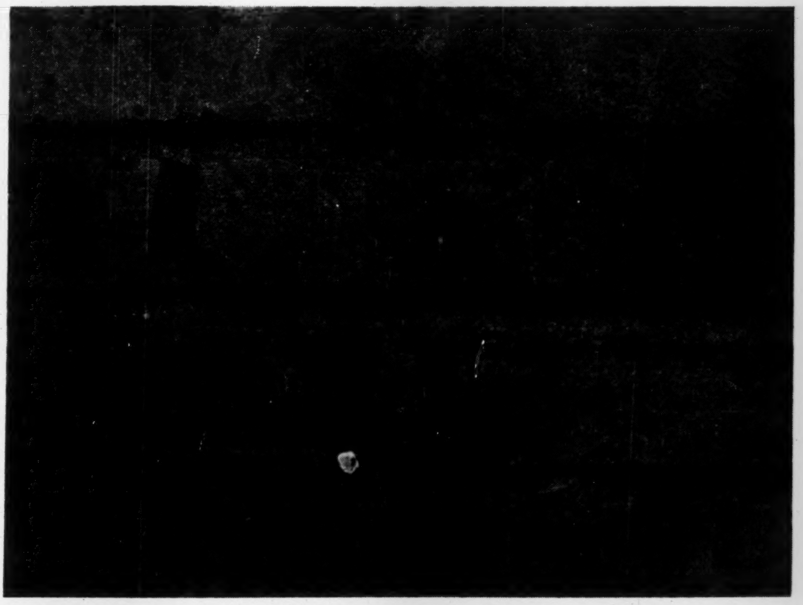

Fig. 5.—Close-up View of "Tooled" Mortar Joints in Pier Built with Chicago Common Brick Laid with 1:¼:3 Cement - High - Calcium Lime Putty - Sand Mortar by Volume.

Photographed November 1936 at age of 3 months.

A concave tooled joint is usually formed by drawing along the joint a metal tool having a suitable radius of curvature on the contact face such that the desired concave joint will result and the adjacent brick edges will limit the depth of action. The observed action of such tooling is not to press mortar back into the joint but to cause a lateral flow at right angles to the motion of the tool. This results in bridging the openings between the mortar joint and brick with what, under some conditions, is a paper-thin cover of mortar. This bridging or covering of mortar erodes away after a lapse of time depending upon the severity of exposure and resistance to weathering and the openings between unit and mortar (see Fig. 4) are again exposed. Figures 5 and 6 are pictures of the same portion of a wall built with Chicago common brick laid with 1:$\frac{1}{4}$:3 cement-high-calcium lime putty-sand mortar. The first photograph was made in 1936, the second in 1948. Figure 6 shows that the edges of the tooling marks have disappeared and there is an absence of cracking in the joints as compared with Fig. 2.

From observations and measurements made on the piers reported in Fig. 1 and Table I, the following conclusions and comments appear to be justified.

1. Significant continued expansion of the piers built with mortar containing dolomitic lime did not become evident until January 3, 1939, at which time the readings first exceeded 0.01 per cent increase in length. The initial readings were made on November 30, 1938, the piers having been built September 22 to 24, 1938.

2. In less than two years, the pier laid with 1:1:6 mortar containing dolomitic hydrate had expanded 0.32 per cent on the face with dolomitic finishing lime and 0.43 per cent on the face with dolomitic mason's hydrate. With the corresponding 1:2:9 mortars, the expansions were 0.46 and 0.56 per cent, respectively. It can be concluded that the amount of expansion was related (*a*) to the amount of dolomitic lime in the mortar (1:1:6 compared with 1:2:9) and (*b*) to the nature of the dolomitic lime (finishing hydrate compared with mason's hydrate). In general, the amount of expansion is probably related to the amount and nature of free MgO in the mortar.

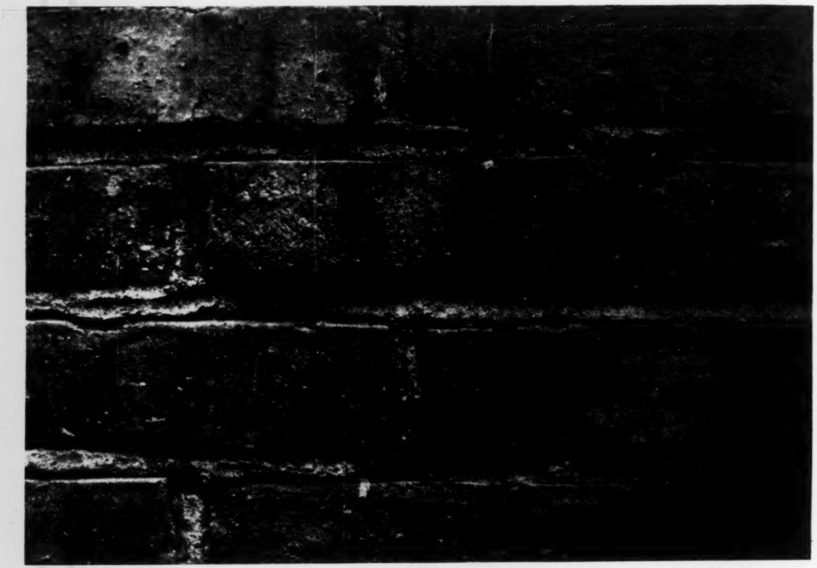

FIG. 6.—Close-up View of Same Portion of Pier Shown in Fig. 5. This photograph was taken in June 1948. Approximate age 12 yr.

Note absence of cracks in mortar and apparent "cracking" between mortar and bricks.

In a period of 2 years and 10 months, the shale-brick pier built with 1:2:9

cement–high-calcium masons hydrated lime–sand mortar increased in length 0.059 per cent, the maximum expansion (0.072 per cent) having been recorded at 1 year 8 months.

3. The effect of changes in temperature on length of piers was very small in comparison with the effect of the expanding mortar in the piers containing dolomitic lime. The decrease in rate of expansion during December, 1939 and January, 1940 for these piers could, however, be ascribed to the effect of lower temperature on the rate of hydration of the free magnesia in the mortar. Conversely, the rapid rate of expansion during the warm months may be explained by increase in rate of hydration with temperature. See paper by Wells and Taylor (5) for data and discussion of effect of temperature on rate of hydration of MgO.

The length changes of the pier laid with high-calcium lime mortar were well correlated with temperature change during the first winter and summer of exposure. The contraction accompanying drop in temperature that occurred the first winter did not, however, take place during the second winter, and an expansion of approximately 0.03 per cent was observed the second spring. The maximum increase in length (0.072 per cent) was recorded in August, 1941, and thereafter the length did not vary more than ±0.01 per cent.

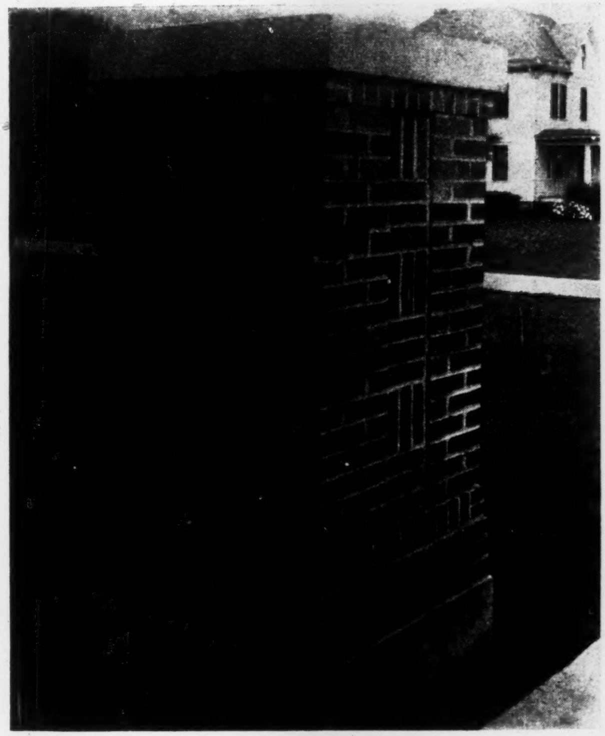

Fig. 7.—Gate Pier at Entrance to Grounds of St. Joseph's School near Bode, Iowa. Photograph made in July 1941 at age of 2 yr 10 months.

Note lifting of the 6 upper courses of brick from the lower courses

4. If expansion had resulted from the freezing of water in the openings between

the bricks and mortar, the amount was small in comparison with that caused by the expansion of the dolomitic mortar during the period covered by the readings on those piers. It will be noted that the highest rate of expansion was during the warm months of 1940. The maximum effect of freezing on volume change would be expected when the specimens were frozen while saturated with water. In the absence of precipitation and humidity records and with temperature measurements made only at the time of reading gages, no estimate can be made concerning this factor.

Observations made over a period of 10 years on wallettes similarly exposed without metal cappings showed (17) "that bricks in the top course (laid with weak mortar) frequently became loosened after a winter's exposure. These same bricks, after several wettings and dryings during the late spring and summer, regained their bond." This loss and recovery of bond was repeated for two or three seasons, but with continued exposure the recementing action ceased. A possible explanation may be that the soluble constituent (lime) had either leached out of the mortar or had become inert through recarbonation. The association of heavy efflorescence, identified as calcium carbonate, with the high-lime mortars lends support to leaching as an explanation.

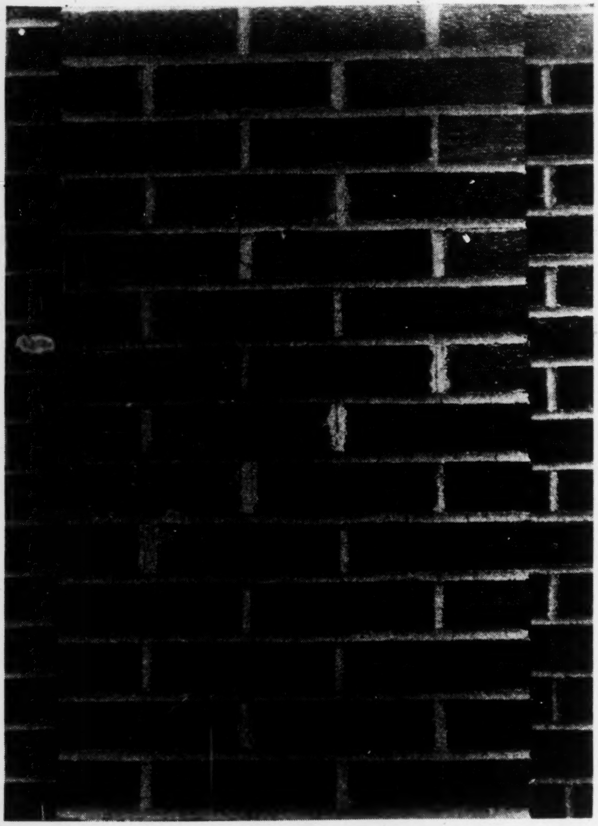

Fig. 8.—Close-up of Chimney on St. Joseph's School Photographed at Age of 2 yr 10 months. Note cracking in bed joints of mortar.

As was pointed out by Wilson (19), free entry of water into masonry is required to dissolve and transport sufficient lime to cause efflorescence and scumming. McBurney's data (17) indicate that exposure to weather tends to decrease water permeability of masonry specimens unless disintegration takes place.

5. Since the pier laid with mortar containing high-calcium lime was not built with Chicago brick, the possibility may be considered that the Chicago brick contributed to or was responsible for the expansion observed in the piers laid with mortar containing free magnesia. Although the lime pebbles characteristically found in these brick are dolomitic and will spall the surfaces of the bricks under some conditions of exposure, the effect on expansion of the piers is considered to be negligible. The reasons for this opinion are: (*a*) the lime pebbles hydrate very quickly and spalling takes place in a few days or not at all; (*b*) the bricks in question had been exposed to the weather for two years before use and complete slaking of free lime would seem assured; and (*c*) similarly exposed piers of Chicago brick laid with high-calcium 1:¼:3 cement-lime-sand mortar showed no evidence of the cracking patterns observed with the piers laid with mortars containing dolomitic lime, (see Fig. 6).

In recapitulation, the maximum increases in length recorded in these tests were 0.072 per cent (1:2:9 mortar using high-calcium lime), 0.32 and 0.43 per cent (1:1:6 dolomitic), and 0.46 and 0.56 per cent (1:2:9 dolomitic). The amount of expansion caused by the presence of incompletely hydrated dolomitic lime in the mortar was affected both by the amount of lime in the mortar and by the nature of the lime. Length changes in the pier built with shale brick and with a mortar containing high-calcium lime were significantly associated with temperature changes. The principal effect of temperature on the piers containing dolomitic lime was to change the rate of expansion. No evidence on the effect of wetting and drying or the action of freezing on length changes was provided.

Parochial School in Iowa:

In the spring of 1941, information was received from the Structural Clay Products Inst. that the engineers of the Institute had recently examined seven masonry structures in Iowa, all of which showed excessive cracking. The masonry units (brick and tile) used in these buildings were supplied by several different manufacturers. The one common factor was a particular brand of masonry cement. One of these buildings, the St. Joseph's Parochial School, near Bode, Iowa, was visited on June 28, 1941, and inspected in the company of the architect, contractor, and the Pastor, Father Theobald. The following description is based upon notes taken at that time, to which are added observations made by F. O. Anderegg, formerly Director, Building Materials Research, John B. Pierce Foundation, who inspected the school in 1943.

The St. Joseph's School is a 2-story structure of brick with structural clay tile back-up, foundations of concrete, concrete-slab floors, and a flat wooden roof deck with parapets. The school was built in 1938 and completed by Labor Day of that year. Cracking of the masonry was observed before occupancy, and some repairs were made.

Two brick gate piers were noted. One of these was hollow and showed a relatively slight amount of cracking in the mortar joints. The interior of the second pier had been filled with brick bats and mortar from the mason's boards and mixing boxes. The condition of this pier in 1941 is shown in Fig. 7. A large horizontal crack had formed 6 courses down from the concrete cap. A smaller horizontal crack was also evident 5 courses below the large crack. In a photograph of this same pier taken in 1943 there is some evidence of horizontal expansion, indicated by vertical cracking near corners. The concrete cap had subsequently lifted, leaving an opening between the concrete and the top of the brick soldier course.

Figure 8 is a close-up showing cracking of mortar joints in a chimney forming part of the school building. Compare the cracking pattern within the mortar with that shown by Fig. 2 (Piers at National Bureau of Standards). The differences may be ascribed to the differences in restraint and loading of the two structures or to the effect of heat at an early age in the chimney. The cracking pattern shown in Fig. 8 does not, however, resemble that usually resulting from heating. Among other observed phenomena were the following:

The cut stone cross set in the brick work on the front of the school had two breaks in its stem. These breaks apparently resulted either from tension or flexure.

Bowing outward of exterior masonry walls was observed. Maximum bulging of $2\frac{3}{8}$ in. in a 25-ft vertical height was measured by reference to a plumb line. The maximum bulging occurred halfway between the second floor line and roof.

The corners of the concrete foundation had cracked. The shearing cracks extended diagonally upward into the masonry (see Fig. 9). The concrete foundation was free from cracking below grade where viewed from the inside (basement walls).

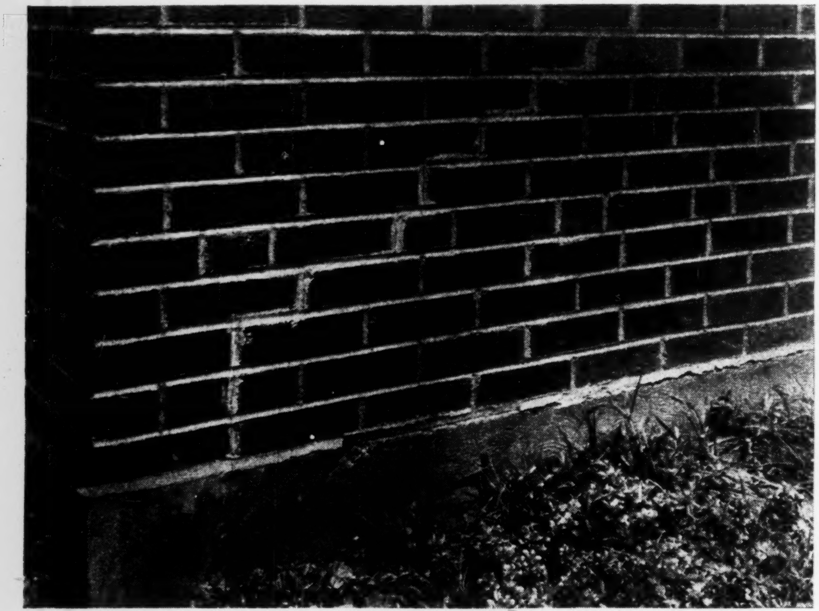

Fig. 9.—Corner of St. Joseph's School near Grade, Photographed at Age of 2 yr 10 months.

Note diagonal crack through masonry and concrete foundation and the condition of bed joint separating concrete and masonry at right of diagonal crack in concrete.

The frames of two fire-escape doors had lifted. When examined by Mr. Anderegg in 1943, a tapered strip $\frac{1}{2}$ in. at one end and $\frac{3}{4}$ in. at the other had been attached to the bottom of one of these doors to fill the space resulting from this lifting.

Jamming of fenestration was noticeable in 1941. Window frames which originally extended $\frac{3}{4}$ in. above their lintels, in 1943 failed to reach the lintels by $\frac{1}{4}$ in.

The vertical joints in the stone belt course at the base of the parapets had opened.

The coping stones on the parapet had also separated at their vertical joints. The appearance resembled what would have resulted from laying the units on an elastic base and stretching the base.

The corners of the parapet had noticeably been moved outward.

The gymnasium roof, originally designed to drain to one corner, had moved so that it no longer drained.

Large horizontal cracks in plaster surfaces applied to structural clay tile backing outlined the bed joints in the masonry. There were, in addition, irregular large vertical cracks. A finer pattern of map cracking was observed within the areas outlined by the large cracks.

When St. Joseph's was inspected in June 1941, no cracking was observed in the brickwork of the Rectory. According to report, cracking took place suddenly and audibly during a rainstorm in the autumn of 1941 with resultant permeability to water.

The above observations would seem reasonably explained by expansion of the masonry. This expansion is ascribed to the mortar for the following reasons: (1) A particular brand of masonry cement was the one material common to all of the seven buildings which had been reported as cracking and (2) masonry of brick and tile from the same source when built with other mortars was free from indications of expansion.

Mr. C. M. Dodd (Head, Department of Ceramic Engineering, Iowa State College, Ames, Iowa) had collected samples of the St. Joseph's material including unused masonry cement left over from the original construction. The following is abstracted from a report made available through his courtesy: From chemical analysis of the masonry cement (made by Mr. Harvey Diehl and Donald E. Howe) and from petrographic examinations (made by Mr. John T. Lonsdale) it was concluded that the masonry cement was essentially a hydraulic dolomitic hydrated lime. In the words of Mr. Lonsdale "All the evidence secured points to the conclusions that the original material . . . was a slightly impure calcium magnesium carbonate rock. Commercial treatment of the material has produced a material which in the unslaked condition consists of a small amount of calcium aluminate and calcium silicate compounds of the cement type with the rest of the mixture being (other) magnesium and lime compounds." The average of three analyses made by Diehl and Howe is as follows:

	Per cent
Loss on ignition	13.26
SiO_2	12.94
Fe_2O_3	1.81
Al_2O_3	2.55
CaO	40.03
MgO	27.86
Loss on drying	0.87
$K_2O + Na_2O$ (not determined)	...
SO_3 (not present by quantitative test)	...
Total	99.32

Mr. Dodd also made autoclave tests on samples of brick and mortar taken from the gate pier shown in Fig. 7 and on mortar samples made with the masonry cement and sand secured from the contractor and from the school. These tests were made at 120-psi steam pressure acting for $2\frac{1}{2}$ hr. The following results were reported:

Material	Expansion, per cent
Brick	No effect
Mortar from pier (age 3 yr)	3.3 and 3.6
Portland cement, neat	0.26
Masonry cement, neat (from school)	41.6
Masonry cement, neat (from contractor)	33.3
Masonry cement and portland cement, neat 1:1 by volume (school)	16.7
Masonry cement and portland cement, neat (contractor)	Broken

Various other combinations such as 1:3 masonry cement–sand, plain and with $\frac{1}{10}$ part of added portland cement, were also autoclaved. Sand from the St. Joseph's School was compared with standard Ottawa sand, 20 to 30 mesh, in these mortars, and check specimens also were made with water from the construction site compared with distilled water. All of these specimens broke or disintegrated on autoclaving. After considering these various possible factors, Mr. Dodd concluded: "This leaves only one material which could have caused the expansion . . . " (the magnesian masonry cement).

The analyses and tests made at Iowa State College checked very closely with the results of similar examinations previously made at the National Bureau of Standards. Figure 10 shows the results of autoclave tests made at the National Bureau of Standards on four 10-in. bars identified as follows: (*a*) 1:3 portland cement–sand by volume; (*b*) 1:1:6 portland cement–masonry cement–sand by volume; (*c*) 1:1 portland cement–masonry cement neat by volume; and (*d*) neat masonry cement. The magnesian masonry cement used in these tests was supplied to the Bureau by the contractor who built the St. Joseph's School and, according to him, was from a portion of the material remaining from that

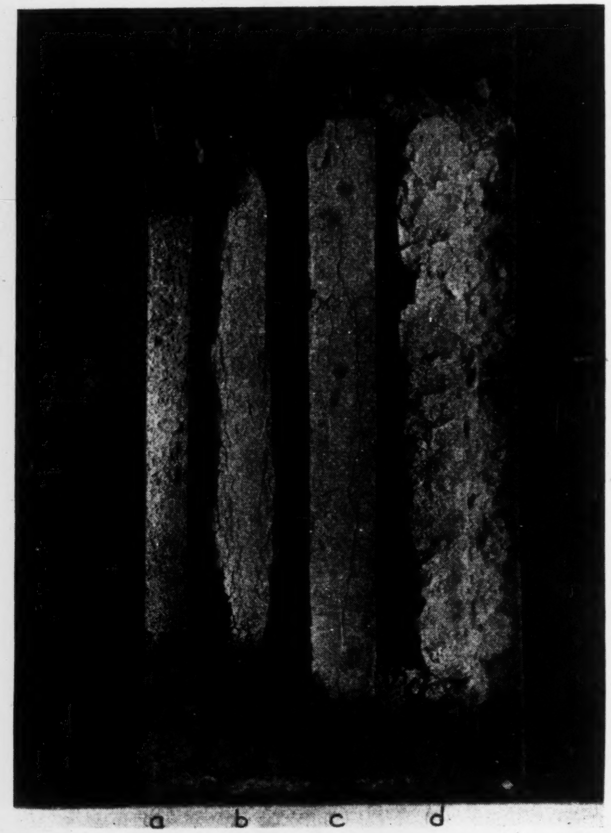

FIG. 10.—Results of Autoclaving Mortar Test Bars by the Method of Test for Autoclave Expansion of Portland Cement.

Specimen *a* is 1:3 portland cement-sand; *b* is 1:1:6 portland cement-magnesian masonry-cement sand; *c* is 1:1 portland cement magnesian-masonry cement; *d* is neat magnesian-masonry cement. The masonry cement is unused material from St. Joseph's School.

job. Another portion from the same sack was used in the tests at Iowa State College. Mr. Dodd tested, in addition, masonry cement of the same brand which had been stored at the school. This is the material indicated as "from school" in the tabulation of his results. Mr. Dodd considers that the greater expansion of the "from school" material is explained by that sample being taken from a previously unopened sack. All samples were approximately three years old at the time of test.

Neither the analyses and examinations made by the National Bureau of Standards nor those reported by Mr. Dodd afford a definite answer to the question as to whether the iron, alumina, and silica in this masonry cement were from added portland cement or were naturally present in the limestone. If the first is true, the cement is a dolomitic hydrated lime to which had been added a small quantity of portland cement. Otherwise, it is a hydraulic, dolomitic, hydrated lime as suggested by Mr. Dodd. In either case, a large quantity of free magnesium oxide was present.

To recapitulate, the St. Joseph's School exhibited evidences of movement reasonably explained by expansion of the masonry. This expansion is ascribed to delayed hydration of magnesium oxide in the magnesian masonry cement used in the mortar. Tests and analyses of samples of the cement confirm this conclusion.

Discussion

The following is quoted from a letter dated January 13, 1951, from Father Theobald, Pastor of St. Joseph's: "All the joints were taken out about an inch and then the entire building repointed. The mortar joints on the house were waterproofed and have not given any trouble since. The east wall, south of the entrance and the opposite wall on the west, were taken down to the first floor and then rebuilt. . . . Very few cracks have developed in the past five years."

The delayed cracking on the Rectory of St. Joseph's and the reported successful repair of the school in 1945 without subsequent cracking raises questions as to the time element. The rate of hydration of magnesium oxide, as shown by Wells and Taylor (5), is influenced by the temperature during hydration. The rate of hydration is also influenced by the burning history of the stone and by the nature and amount of other constituents such as alumina and silica. The nature of the exposure of the masonry is another factor, since water is necessary for the progress of hydration. It follows, therefore, that neither the time at which trouble starts nor the time required for hydration to become sufficiently complete so that further expansion is negligible can be predicted with any certainty. From the report on St. Joseph's, it would appear that early repair was useless, since existing cracks reopened and new cracks formed. On the other hand, repairs made after seven years appeared to be more effective.

The sudden development of cracking in the Rectory at three years is comparable with the observations on bulging of white coat on plaster reported by Wells, Clarke, Newman, and Bishop (7). They state "several years (from about 5 to 15 but usually from 8 to 9) elapse before the blisters or bulges begin to appear, and thereafter the number and extent of failures increase as the age of the building increases." The difference in time before development of visible expansion on plaster white coat and on masonry appears reasonable in view of the difference in exposure to moisture. The first evidence of expansion in the St. Joseph's School was noted in the parapet. Evidence obtained in studies of disintegration shows conclusively that, exceeded only by masonry exposed to soil, parapets are the most subject to disintegration by weathering.

The exposure of the test piers of the National Bureau of Standards corresponded to that of an unprotected parapet. Although expansion was still proceeding at a rapid rate at the end of two years when readings were discontinued, no visible change was observed after four years beyond what could reasonably be ascribed to weathering. Further evidence that the hydration of free magnesia will proceed to completion in a few years is provided by the results of the tests made by Mr. Dodd on 3-yr old mortar from St. Joseph's compared with unexposed masonry cement. There is, however, some question concerning the presence of sand on the effect of an autoclave test because of pozzolanic action.

To recapitulate, repair of masonry built with an expansive mortar is only of temporary value unless hydration of free oxide has approached completion. Further consideration of repair will be given under *Recommendations*.

Consideration of the history of plaster failure resulting from expansion of white coat as reported by Wells and his coworkers (7) explains in part why so little recognition has been given to expansive mortar as a cause of cracking and why so few examples have been reported or noted. The type of lime now known to be responsible for white-coat bulging was being used as early as 1910. The theory of the delayed hydration of free magnesium oxide with consequent expansion was well enough known so that this explanation was given in 1923 for a plaster failure in Cleveland, Ohio (the Mt. Sinai Hospital). As far as is shown by public record, no other examples of this type of failure were known until after the publication of the paper by Wells and Bishop (5) in 1937. To contradict the findings of this paper, it was first claimed that white-coat failures were nonexistent. This claim was abandoned when surveys and spot checks showed conclusively that bulging of white coat was the rule rather than the exception when "N lime"[3] had been used on plaster over masonry or concrete backings and sufficient time had elapsed.

Cracking of masonry is obviously a more complicated phenomenon than is bulging of white coat on plaster. That bulging results from an increase in area of the white coat over the area to which the white coat is applied, is an unescapable conclusion. The possibility that the base shrank can nearly always be eliminated by inspection. Furthermore, the materials used in plaster are few and relatively simple in composition. Masonry, on the other hand, is a heterogeneous combination of units and mortar subject to stresses and resulting strains from both internal and external sources. Some masonry units shrink, others may expand, depending upon composition, nature and previous history. Mortar is popularly believed to shrink and cracking is nearly always ascribed to shrinkage of mortars or units. In consideration of (*a*) the infrequency with which laboratory examinations are made part of investigations of masonry cracking; (*b*) the unlikelihood of structural engineers and architects being acquainted with the theory of magnesia expansion; and (*c*) the relatively little use of "N-type" lime in mortar, it is not surprising that few cases of damage from expansive mortar have been noted.[11] The limited use of

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[11] The author was recently advised of the existence of two acute cases of masonry expansion and cracking on buildings in Wisconsin. Mr. Herbert F. Wustmann, Regional Engineer of the Chicago office of the Structural Clay Products Inst., who had examined one of these buildings, had seen a portion of the present manuscript and remembered the description and photographs of the St. Joseph's School. In a recent letter, the following statement appears concerning one of the Wisconsin cases: "Upon dropping a plumb bob so that its line was coincident with the most outward surface of the bulging masonry, we found the top or parapet masonry 4⅜ in. from the vertical line and the bottom masonry 2⅞ in. from the vertical line. The height of the masonry above the foundation is 21 ft 9 in. to the top of the parapet. The maximum bulge occurred approximately 9 ft 7 in. from the top. The extent of the bulging is almost two times that of the Iowa school outlined in your manuscript." The same brand of magnesian masonry cement was used in both the Iowa and Wisconsin buildings.

"N lime" would be expected. The cost of this lime sold as finishing hydrate is higher in comparison with lime offered as mason's hydrate and "N lime" usually requires soaking for at least over night before it is effective as a plasticizer. One of the properties of "S lime" (pressure hydrate) is that it develops plasticity almost immediately upon the addition of water.

Chemical analyses of mortars from buildings three or more years old will establish the presence or absence of magnesium compounds. Such analyses will not, however, indicate whether the magnesium was originally present as oxide or whether hydration had been substantially completed before setting and hardening of the mortar. The lime, for example, might have been a putty made by prolonged soaking of dolomitic quick lime or by soaking of an "N" dolomitic hydrate. Mortars used since 1947 may have been made with "S lime." If "S lime" or aged putty was used originally, the presumption is that magnesium oxide was not present initially in damaging amounts. To ascribe the damage to this ingredient, it should be shown (*a*) that the damage had resulted from expansion; (*b*) that other factors or causes can be eliminated; and (*c*) that the lime or magnesian masonry cement was unsound as used. The difficulty of establishing with certainty the condition of use and brands of mortar ingredients is well known to those who have had occasion to investigate mortar troubles observed several years after construction. Samples of the original ingredients are rarely available. The St. Joseph's School was an exception.

RECOMMENDATIONS

The following recommendations are limited to consideration of the prevention of and remedies for expansions resulting from the presence of free magnesium oxide in the masonry cement or lime in mortar:

1. Accept for use in mortars only those masonry cements and limes which do not exceed 1.0 per cent increase in length when tested for expansion according to the ASTM Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 49).[8] For slow hardening cementitious materials, the test may be made at 48 hr instead of at 24 hr as prescribed by Method C 151 - 49. For the purpose of these recommendations, hydraulic hydrated lime shall be considered as a masonry cement.[12] The test bars for lime for use in cement-lime mortars shall be composed of a mixture of lime and portland cement in the proportions specified for use on the job.

2. In the absence of tests, lime should be restricted to type S hydrate or to putty made from high-calcium quicklime. Such a putty should be soaked for not less than 24 hr and otherwise handled as prescribed in the appendix to the ASTM Standard Specification for Quicklime for Structural Purposes (C 5 - 26).[13] The use of unslaked quicklime as an ingredient of mortar cannot be too strongly condemned.

3. Costly repairs such as cutting out and repointing of mortar joints should be delayed, if possible, until the hydration reaction has progressed to the stage where further expansion is negligible. If structural failure appears imminent, the masonry should be replaced at once. Painting with cement-water paint and the use of cement grout in cracks will afford temporary relief for water transmission. Organic calking compounds for filling cracks are not recommended because the oils in such materials may adversely affect bond when repointing with mortar or grouting is attempted later.

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[12] Standard Specifications for Hydraulic Hydrated Lime for Structural Purposes (C 25 - 47), 1949 Book of ASTM Standards, Part 3, pp. 187-199.

[13] Standard Specifications for Quicklime for Structural Purposes (C 5 - 26), 1949 Book of ASTM Standards, Part 3, pp. 157-8.

SUMMARY AND CONCLUSIONS

The effect of free magnesium oxide (MgO) in causing the expansion of hardened masonry mortars is discussed. From information available in the literature, from the results of length change measurements on brick piers laid with mortar containing excessive quantities of MgO, and from the examination of buildings, including laboratory tests of masonry materials, it is concluded that the delayed hydration of MgO can cause expansions of sufficient magnitude to produce severe cracking and structural damage in masonry. Some other causes of cracking are listed, and the probable origin of certain openings between units and mortar joints is considered. Recommendations for the prevention of trouble from expansive mortars are offered.

The principal observations and conclusions are the following:

1. The effect of delayed hydration of free-magnesium oxide in causing expansion of concretes and of lime-gypsum white coats on plaster is well known, but the corresponding effect on brick masonry appears to have been generally overlooked.

2. Evidence is presented which indicates that many of the observed openings between bricks and mortar joints are not the result of mortar shrinkage but are caused by certain techniques of the mason.

3. Changes in length measured on piers built with Chicago Common brick and 1:1:6 and 1:2:9 cement-lime-sand mortars by volume showed increases of length of 0.32 and 0.43 per cent with 1:1:6 mortar and 0.46 and 0.56 per cent with 1:2:9 mortar in less than 2 years where the lime was a dolomitic hydrate containing large amounts of free MgO.

4. The amount of increase in length appears to depend both upon the amount of lime in the mortar (1:1:6 compared with 1:2:9) and the nature of the dolomitic hydrate. (Dolomitic finishing lime compared with dolomitic mason's hydrate.)

5. The corresponding increase in length of a pier built with a "light hard" shale brick laid with 1:2:9 cement–high-calcium lime–sand mortar by volume was 0.059 per cent at 2 years 10 months. The maximum increase in length was 0.072 per cent at 1 year 8 months.

6. The results of autoclave expansion tests made on cement-lime mixtures in the proportions 1:2 by volume showed from 12.9 to 17.7 per cent increase in length where the dolomitic finishing hydrated lime was used, and the corresponding expansion for the high-calcium hydrate was 0.18 per cent.

7. A number of buildings in Iowa were reported to be undergoing excessive cracking in their masonry. Various brands of brick and structural clay tile were represented in these structures, but a brand of magnesian masonry cement, shown by analysis to be essentially hydraulic dolomitic hydrated lime, was common to all of them. One of these buildings, St. Joseph's School near Bode, Iowa, was examined in detail and it was concluded that the observed behavior was caused by expansion of the masonry.

8. Laboratory examinations were made of masonry materials from St. Joseph's School. These examinations included chemical analyses and autoclave tests for soundness as measured by volume changes. Samples of the magnesian masonry cement approximately three years old at the time of test gave length increases exceeding 30 per cent when tested for autoclave expansion. Examinations of other masonry materials gave no evidence of volume change. The cause of the expansion was, by elimination, the unsoundness of the magnesian masonry cement.

9. Early repairs made on St. Joseph's School were ineffective, since motion continued with old cracks reopening and new cracks forming. Repairs made at age of 7 yr were reported to be effective 5 yr later.

10. It recommended that masonry cements and cement-lime mixtures for use in mortar be required to pass an autoclave test for soundness with a permitted gain in length of not more than 1.0 per cent.

Acknowledgments:

In addition to those mentioned in the body of this paper, acknowledgment is made to the following persons: H. C. Plummer and C. T. Bridgman of the Structural Clay Products Inst. for their aid in arranging inspections; L. S. Wells and Walter F. Clarke for their examinations and advice on mortars; and to Messrs. Perry H. Petersen, M. Arnold Copeland, and Russell C. Brink for strain-gage measurements on masonry piers.

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(6) L. S. Wells, W. F. Clarke, and E. M. Levin, "Expansion Characteristics of Hydrated Limes and the Development of an Autoclave Test for Soundness," *Journal of Research*, Nat. Bureau of Standards, Vol. 41, September 1948, pp. 179–204 (RP1917).

(7) L. S. Wells, W. F. Clarke, E. S. Newman, and D. L. Bishop, "Investigation of Failure of White-Coat Plaster," Building Materials and Structures, *Report BMS 121* (1951).

(8) E. D. Campbell and A. H. White, "Some Conditions Influencing Constancy of Volume in Portland Cement," *Journal*, Am. Chemical Soc., Vol. 28, p. 1273 (1906).

(9) J. C. Pearson, "Shrinkage of Portland Cement Mortars," *Proceedings*, Am. Concrete Inst., Vol. XVII, p. 133 (1921).

(10) F. O. Anderegg "Some Properties of Mortar in Masonry," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, pp. 1130–40 (1940).

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(14) N. Stutterheim, T. L. Webb, and B. Uranovsky, "Developments in Research on the Burning and Hydration of Lime and on Its Use in Building," National Building Research Institute Council for Science and Industrial Research, (South Africa), Div. 2, pp. 120–126, Bldg. Res. Congress, London (1951).

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(16) J. C. Pearson, "Measurement of Bond Between Brick and Mortar," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 867 (1943).

(17) J. W. McBurney, M. Arnold Copeland, and R. C. Brink, "Permeability of Brick Mortar Assemblages," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, pp. 1333–1348 (1946).

(18) L. A. Palmer and D. A. Parsons, "A Study of the Properties of Mortars and Brick and Their Relation to Bond," *Journal of Research*, Nat. Bureau of Standards, Vol. 12, May 1934, pp. 609–644 (RP683).

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DISCUSSION

Mr. C. E. Wuerpel[1] (*presented in written form*).—The excellent presentation by Mr. McBurney, particularly of the difficulties experienced at St. Joseph's School in Iowa due to the delayed expansion of incompletely hydrated magnesium oxide, is supported by similar distress which has occurred in several structures in Wisconsin and northern Illinois within the past year.

Outstanding in this recent experience of destructive expansion is a warehouse building of approximately 1,525,000 sq ft floor area of clay-brick faced concrete-block bearing wall construction. The specifications required use of a mortar containing equal parts of portland cement and lime. However, the contractor obtained permission to use a masonry cement which was alleged to consist of a blend of essentially equal parts of portland cement and hydrated dolomitic lime. The building was completed during the early summer of 1950. During the fall and winter of 1951 very appreciably expansion became evident, which by the spring of 1952 had become severe. Illustration of typical expansion at various points in this structure is given in Figs. 11, 12, and 13.

The masonry cement used met the requirements of ASTM Specification C 91 – 50, but it was an unsound product obtained by blending, not intergrinding, portland cement with evidently incompletely hydrated dolomitic lime. The expansion resulted from the delayed hydration of the free magnesia as the exposed wall grew saturated with the rain and melting snow of the first winter.

Tests made by the writer on specimens of the aged mortar extracted from the interior (unaffected) walls and from the seriously disintegrated parapet shown in Fig. 11 indicated that very appreciable potential expansion still remains in the mortar. The specimens of mortar were cut by means of a diamond saw into suitable sized bars and autoclaved. The results of the tests are given in the accompanying Table I. Figure 14 shows graphically the complete disintegration of the bars by the autoclave test, in contrast to normal behavior of sound mortar.

Mr. Henry M. Reitz[2] (*by letter*).—An interesting experience with the expansion of oxides of magnesium, calcium, and iron recently came to the writer's attention. A large, heavy manufacturing plant was built during World War II. This plant had not been used following the cessation of hostilities until it was bought for a basic processing plant during 1951. Very meager record information was available. Differential heaving of heavy concrete slabs was noted at certain isolated locations. This heaving occurred over a period of a few months in temperatures well above freezing. It was important to determine what caused the heaving.

An investigation disclosed that the backfill material beneath the slabs was a mixture of alluvial materials, overlain by a light-colored, ashy material and used core or molding sands. Observation in test pits indicated that the heaving was the result of a relatively thin layer of this light-colored, ashy material which varied in thickness from 6 to 18 in. A commercial chemical analysis of this material indicated a combined CaO-MgO content of approximately 30 per cent, with additional R_2O_3 content which was mainly Fe_2O_3 in excess of 10 per cent, and the loss on ignition approached 10 per cent.

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[1] Technical Director, Marquette Cement Manufacturing Co., Chicago, Ill.

[2] Assistant Professor, Washington University, St. Louis, Mo.

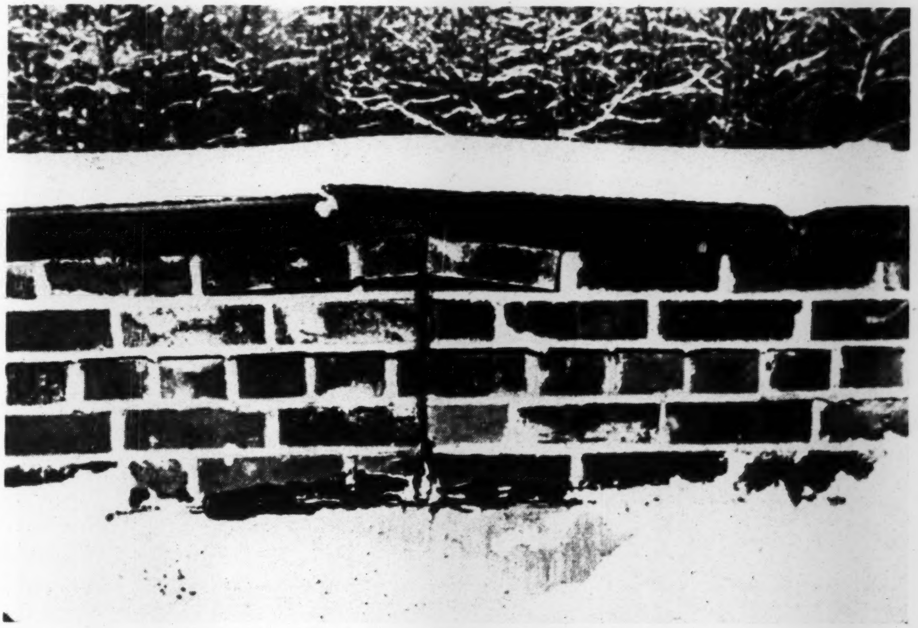

FIG. 11.—Seriously Disintegrated Parapet.

Questioning of craftsmen familiar with the construction of the plant disclosed that hot slags directly from furnaces of a nearby plant had been used for filling. These slags were the light ashy material. Since volumetric expansion to the simpler forms of hydroxides or carbonates would more than double the volume of the oxides, it was concluded that the hydration or possibly carbonation of oxides of magnesium, carbon, and iron were responsible for the slab heaving observed.

MR. F. O. ANDEREGG[3] (*by letter*).—Mr. McBurney's paper develops the thesis that masonry mortar troubles are more likely to be caused by forces resulting from mortar expansion than from shrinkage forces. His results on expansion of brick panels laid with dolomitic limes are similar to ones the writer published more than 20 years ago.[4] The writer is also in agreement, after more than 25 years of experimenting, with his conclusion that most of the openings in masonry through which water penetrates between the mortar and the units are the "result of the technique of the mason."

The troubles in Iowa and Wisconsin described by the author and by Mr.

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[3] Consulting Specialist on Building Materials, Somerville, N. J.

[4] F. O. Anderegg, "Watertight Brick Masonry," *Architectural Record*, September, 1931.

Wuerpel might well have been avoided by a proper ASTM specification. After a study of the photographs taken on these jobs it is not surprising that the proposal should be made that bars of neat masonry cement should show not more than 1 per cent autoclave expansion at the age of 48 hr.

On the other side of the question, the writer has been confronted on many occasions with troubles apparently caused by mortar shrinkage. A few years ago a report describing the difficulty in getting tight pointing work on granite masonry was made to Committee C-12 on Mortars for Unit Masonry. This was found to be due to a combination of faulty technique on the part of the masons, a mortar deficient in plasticity and stickiness, and some shrinkage tendency. Figure 15 is a photograph of typical pieces of mortar taken from joints in this granite masonry, after painting with a dye solution. Figure 16 shows a wall of Indiana limestone,

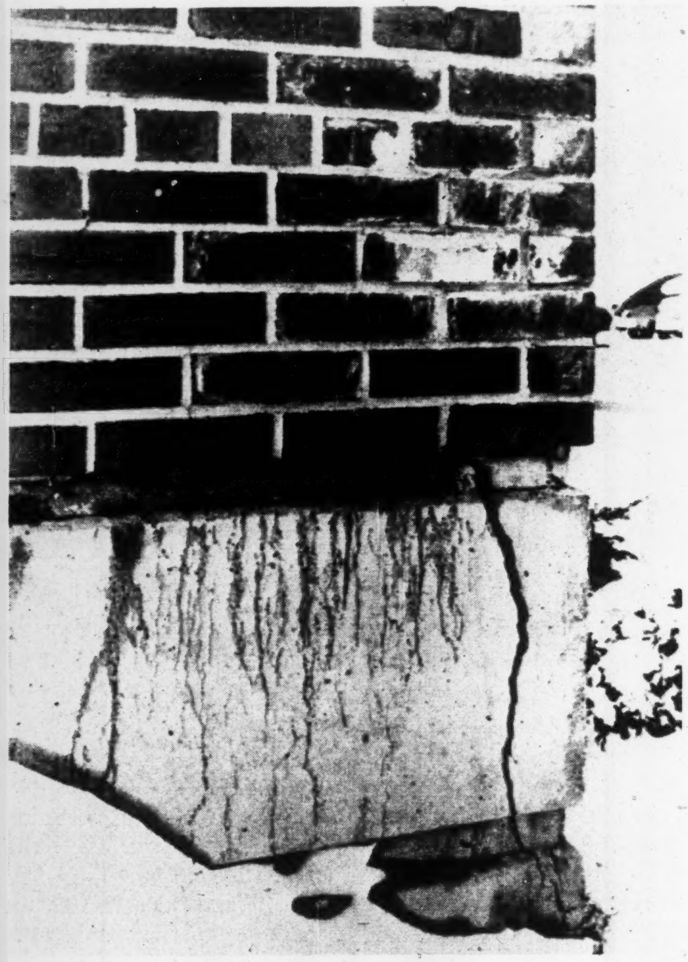

FIG. 12.—Expansion of Walls with Resultant Rupture of Concrete Foundation.

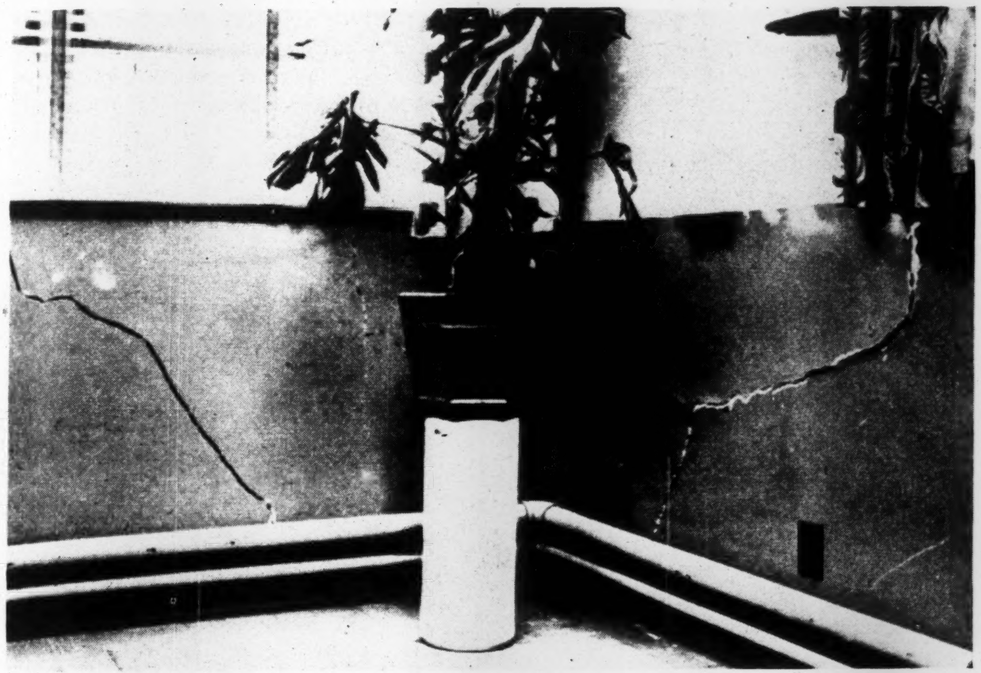

FIG. 13.—Cracking of Interior Plaster near Corner Due to Expansion in Walls.

where much of the pointing mortar was simply resting in the joint without bond to the stones. When the water jet shown in the photograph was applied to clean the stone surface, much of the pointing mortar was knocked out. The grime on both sides of the mortar pieces so removed showed the lack of contact with the stone. Many stone jobs seem to be characterized by incomplete bond of such pointing mortars.

When it comes to parging mortars and stuccos, low permeability to moisture is desired. Where color is not important, some people add iron filings and ammonium chloride to produce a small, controlled expansion early to offset shrinkage tendencies. One prominent waterproofing company has stated, "When we put an ironite treatment on the inside of a basement wall, we can give a 5-yr guarantee against leakage."

Another reaction which might produce expansion comes from the hydration of

TABLE I.—EXPANSION OF MORTAR SPECIMENS UPON AUTOCLAVING AS PRESCRIBED IN ASTM SPECIFICATIONS C 151 – 49.

Specimen[a]	Initial Length, in.	Final Length, in.	Length Change, in.	Expansion, per cent
AUTOCLAVED 3 HR				
E	10.96	Disintegrated	Disintegrated	...
F	9.94	Disintegrated	Disintegrated	...
G	9.96	Disintegrated	Disintegrated	...
H	6.74	7.50	+0.76	11.3
M-1	10.1390	10.1482	+0.0092	0.09
AUTOCLAVED 1½ HR				
A	6.98	8.92	+1.94	27.8
B	10.98	11.10	+0.12	1.1
M-2	10.1393	10.1465	+0.0072	0.07
M-3	10.1385	10.1452	+0.0067	0.07
AUTOCLAVED 45 MIN				
C	10.98	11.62	+0.64	5.8
D	6.98	7.12	+0.14	2.0
M-4	10.1365	10.1418	+0.0053	0.05
M-5	10.1389	10.1444	+0.0055	0.06

[a] Specimens A through H are from "warehouse" mortar.

Specimens M-1 through M-5 are 1:3 mortar specimens prepared in the laboratory from sound portland cement-limestone-base masonry cement.

MgO. However, the amount of the MgO and its physical condition must be under rigorous control so that the degree of expansion should be close to that of shrinkage. Moreover, the expansion would need to take place early, while the mortar has a certain minimum amount of plastic flow, to permit it to adjust itself to the expanding action. That some mortars have greater ability in this respect than others must be taken into account.

This whole question needs careful study to provide the basic information on which to set up a fair and scientific specification. An experimental study not only of pointing mortars for brick and stone work, but also of general masonry mortars for whole joints has been started in the writer's laboratory. Particular attention will be given to the possibility and desirability of securing small expansions early. The indignation naturally resulting from consideration of the Iowa and Wisconsin jobs should not lead to setting up specifications which may fail to secure the best all around results and tend to put out of use certain masonry cements with long and impressive records of satisfactory field performance.

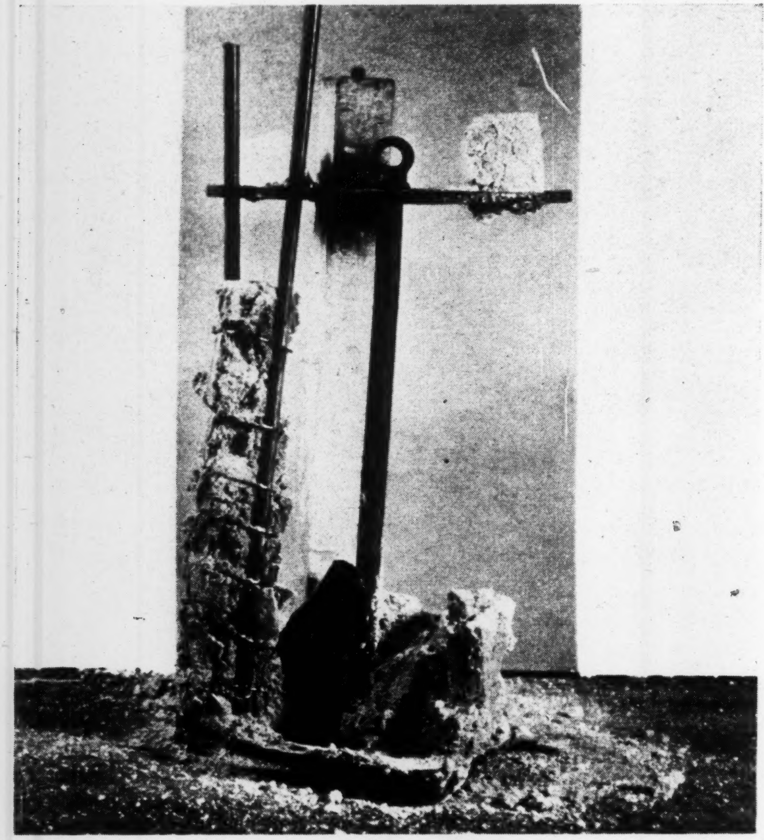

FIG. 14.—Complete Disintegration of Unsound Mortar from Warehouse Parapet.

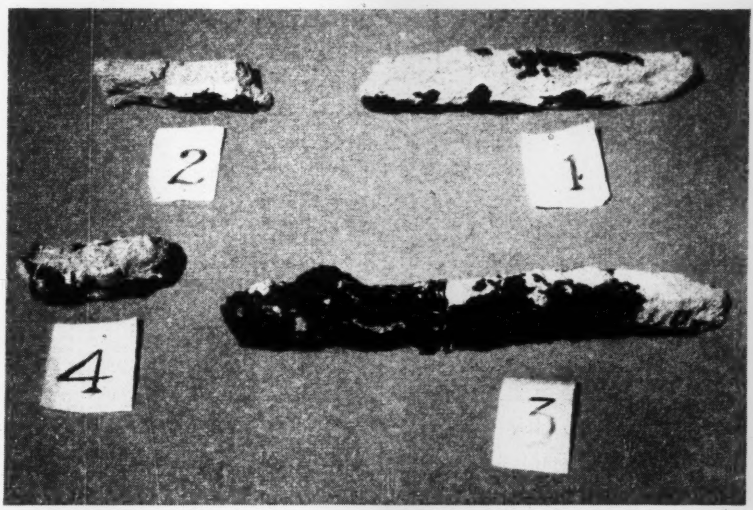

FIG. 15.—Pointing Mortar Taken from Granite Masonry After Painting the Joints with a Dye Solution.

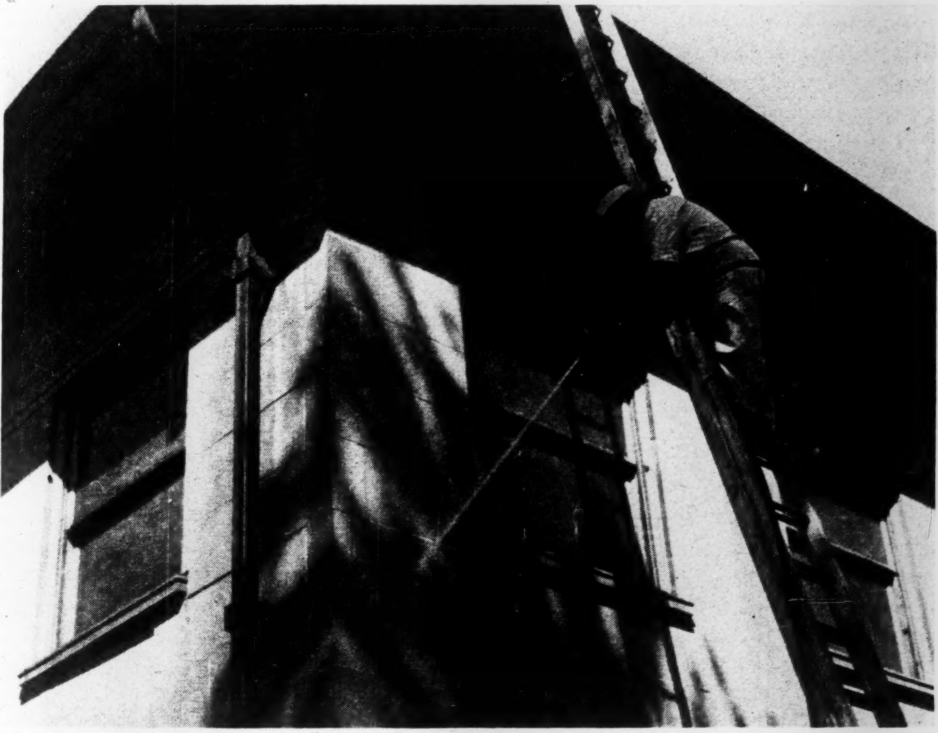

FIG. 16.—Pointing Mortar Washing Out of Indiana Limestone Masonry Joints by a Water Jet.

MR. C. C. CONNOR[5] (*by letter*).—Mr. McBurney was not very explicit as to whether the condition of masonry cracking in the building he described was unusual or of frequent occurrence, but the reader cannot avoid getting the impression from the paper that the major causes of mortar joint cracking are the expansion of normally hydrated high-magnesium limes and openings caused by workmanship.

No one is likely to question that cracking in masonry can result from the expansion of unsound cementitious materials in mortar or that the *N*-type hydrates of high-magnesium lime tend to expand in the autoclave, but the building condition described seems to be most exceptional. The writer has never identified such a condition in the examination of several hundred buildings. Certainly no such condition occurred in any of the 84 building units from which he gathered the data on mortar joint cracking which were reported to the Society.[6, 7]

The mortar joint cracking in those building units varied from 2.5 to 68.3 ft of cracks per 100 ft of mortar joint, or from 2.5 to 68.3 per cent. The lowest cracking measurement was with a high-lime mortar containing an *N*-type high-magnesium hydrated lime and the high figure of 68.3 per cent was with a mortar containing 25 per cent of high-calcium hydrate. There were several instances where a high-lime mortar containing an *N*-type high-magnesium lime produced cracking of less than 10 per cent, which is far below the average. The cracking varied widely with each of the various limes, and no correlation could be found between the kind of lime and the amount of cracking, although it was thought that all of the limes had good plasticity. There were definite indications that the cracking was decreased by a moderate rate of absorption of the bricks and a high percentage of lime in the mortar. Concave tooling of the joints also proved to be beneficial. The *N*-type magnesium limes gave good results if all the other factors were favorable.

The amount of cracking seemed to depend on factors other than the kind of lime, and if one or all of the factors of the suction of the brick, the type of tooling, or the amount of lime in the mortar were unfavorable the cracking rose abruptly.

As far as cracking between the mortar and brick being caused by workmanship, the indications were that, if the tooling was good and the mortar workable, openings caused by cutting off the mortar were permanently closed by concave tooling. The building units varied in age from 6 to 23 yr, and if erosion had exposed cracks the cracking should have consistently increased with the age of the building. Such was not the case, and some of the older buildings had very low cracking.

It is an accepted fact that various mortar mixes differ in their volume change subsequent to hardening. When this volume change produces a definite growth in cracks of considerable width, the conclusion that shrinkage has occurred appears to be unescapable. Concrete shrinks as it dries, and so does mortar. Some mortars have a considerable residual shrinkage after each cycle of wetting and drying. The evidence of many field observations indicates that shrinkage after hardening is a major cause of mortar joint cracking.

Mr. McBurney has had a great deal of experience with brick masonry, and it would be most unfortunate if his paper were to be wrongly interpreted. To clarify the matter the writer would like to ask him three questions.

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[5] Building Inspection and Maintenance Engineer, New Jersey Bell Telephone Co., Newark, N. J.

[6] C. C. Connor, "Resultant Separation Cracking Between Various Mortars and Brick in Existing Brick Structures," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 454 (1934).

[7] C. C. Connor, "Factors in the Resistance of Brick Masonry Walls to Moisture Penetration," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1020 (1948).

1. Does he feel that the evidence given in his paper justifies a conclusion that shrinkage in mortar is an infrequent cause of cracks at or in the mortar joints?
2. Does he believe that expansion caused by *N*-type high-magnesium lime hydrates and openings caused by workmanship are the major causes of mortar joint cracking?
3. Does he regard the mortar condition in the building he described as unusual or of frequent occurrence?

MR. T. L. WEBB[8] (*by letter*).—Since 1945 about 60 cases of expansive mortar failure similar to those described by the author have been encountered in South Africa and investigated both in the field and the laboratory.[9] These failures range in severity from barely discernible cracks to extremely severe structural failure in which the expansion in each mortar bed may be as much as 0.1 in. Such cracks generally outline the bed joints in masonry[9] in a manner similar to that described by the author. Generally, the cracking is more severe in the upper courses of masonry, and the mortar is usually friable and often exhibits severe popping. Observations similar to the author's that lintels were lifted off window frames were made. In one case a concrete beam spanning two ornamental pillars was lifted approximately $\frac{1}{2}$ in. off the heads of the pillars by the expanding masonry in which its ends were set. It was also found that, as the author reports, early repair was useless since expansion merely continued.

In dealing with such cases, the practice has been adopted of measuring the distance between studs on opposite sides of a crack by means of a strain gage, and, when expansion has ceased, effecting repairs which are then permanent.

In each of the failures investigated, a magnesian or dolomitic lime was involved, but, since the use of high-calcium limes in building is uncommon in South Africa, this is less significant than it may appear to be. There is also no doubt that these failures were due to the expansion of the lime.

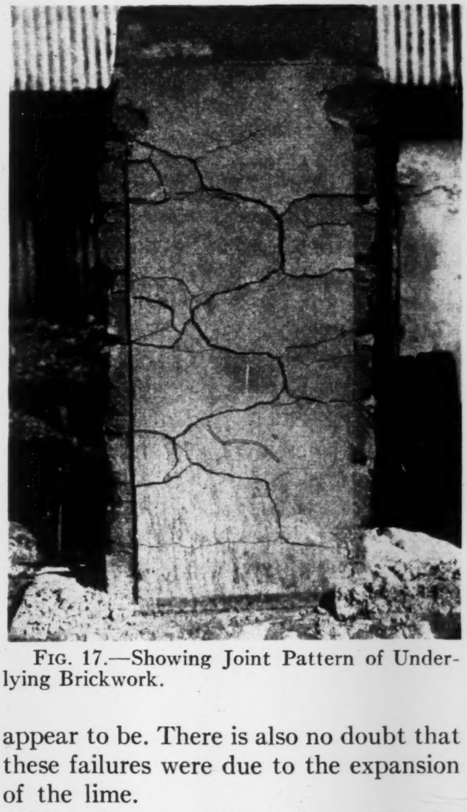

FIG. 17.—Showing Joint Pattern of Underlying Brickwork.

In order to verify and amplify the laboratory work, over 100 walls such as that shown in Fig. 17 have been erected using a 1:4 lime-sand mortar. The limes were calcined in an experimental kiln and normally hydrated. This project has been designed so as to evaluate the various factors which laboratory work had shown to affect soundness and hydration. In Fig. 17, the joint pattern of the underlying brickwork can be clearly seen.

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[8] Senior Research Officer, National Building Research Institute, C.S.I.R., Pretoria, South Africa.

[9] N. Stutterheim, T. L. Webb, and B. Uranovsky, "Developments in Research on the Burning and Hydration of Lime and on Its Use in Building," National Building Research Institute Council for Scientific and Industrial Research (South Africa), Div. 2, pp. 120–126, Bldg. Res. Congress, London (1951).

Some of these experimental walls were built using 1:2:8 portland cement-lime-sand mortar; invariably those walls containing cement showed considerably greater expansions, often two or three times larger, than walls containing the same proportion of the identical lime. This observation is in line with that of Bonnell and Pippard, quoted by the author, and may be due to the greater early rigidity of the cement mortar resulting in the expansion disrupting the masonry. In the less rigid lime mortar a good deal of expansion might be accommodated without disruption or serious dimensional change.

Experimental walls built with 1000 C dolomitic lime mortar without portland cement, using bricks containing about 3 per cent of $MgSO_4$ or alkali sulfates, have shown expansions three to four times larger than the same lime used with bricks free from such sulfates. There is, however, ample evidence that this is not the cause of expansive mortar failure in South Africa.

Walls containing dolomitic lime calcined at temperatures below about 1100 C have shown no unsoundness during 300 days after erection, and strain gage measurements effected by means of a Huggenberger deformeter, over a 20 in. gage length, have shown that such walls have expanded by about 0.15 per cent during that time. Corresponding walls containing a 1200 C high-calcium lime have expanded by 0.06 per cent. These figures are of the same order as the expansion of 0.07 per cent found by the author for sound high-calcium lime mortar piers after 2 yr.

Walls containing dolomitic lime burnt at temperatures between 1150 and 1300 C generally show typical expansive mortar cracking 3 to 6 months after erection, with expansions of 0.4 to 0.8 per cent after 300 days, and walls containing dolomitic lime burnt at temperatures above about 1300 C generally show very severe cracking within about 10 days after erection with expansions of 1 to 3 per cent. Generally, cracking first becomes evident when the masonry has expanded by about 0.20 per cent.

Differential thermal analysis on mortar samples from the walls has shown that those limes showing rapid expansion contain no hydrated MgO, indicating that this very severe form of expansion is due to the hydration of CaO and not MgO. The fact that MgO calcined at temperatures above about 1050 C is known to hydrate slowly[9] and that its hydration both in the autoclave[9] and at atmospheric pressure is accompanied by expansion indicates that the delayed form of expansion is due to the hydration of MgO. Furthermore, an experimental wall containing a magnesite calcined at 1200 C has shown this slow form of expansion. Thermal analyses have shown that hydration of MgO had taken place in such walls.

The 1000 C dolomitic limes in the sound walls had little or no MgO hydrated when the walls were built, but thermal analysis has shown that most, if not all, of this MgO hydrated in the wall subsequent to its erection without causing any expansion.

From this work it is concluded that (*a*) those failures involving severe early expansion are primarily due to the hydration of CaO with the hydration of MgO of secondary significance, (*b*) the delayed form of expansion is due to the hydration of MgO only and (*c*) the hydration of MgO can take place without causing expansion provided that it is calcined at a temperature below about 1050 C. There is reason to believe that the important factor is the rate of decomposition of the raw stone rather than the ultimate temperature reached.

It is thus believed that the author's statement that "it is concluded that the delayed hydration of MgO can cause expansions of sufficient magnitude to produce severe cracking and structural damage in masonry" is correct, but it should be borne in mind that delayed hydration of MgO can also take place in mortar without causing unsoundness.

It is our view[9] that a factor often overlooked when considering the rôle of MgO in limes is that its behavior is profoundly influenced by its history.

The basis for our statement quoted by the author that "no satisfactory correlation appears to have been established between unsoundness tests and the behavior of the materials in practice" is the fact that a number of limes which easily pass the Le Chatelier soundness test laid down in the British Standard 890 for Building Limes cause very severe expansive mortar failure and also that many local limes which prove satisfactory in use, when tested by the autoclave test method as proposed by Wells,[10] have expansions above 7 per cent, more than seven times as high as the 1 per cent limit referred to by the author. Promising correlation is, however, being obtained by using a modified version of the Le Chatelier test.

It would appear that the solution to expansive mortars lies in prescribing a soundness test proven to correlate with the performance of a lime or masonry cement rather than either limiting the MgO content or using an autoclave test with a somewhat stringent limit of 1 per cent, since both of the latter may prove restrictive in that they can often exclude satisfactory materials.

MR. J. W. MCBURNEY (*author's closure*).—The St. Joseph's School was one of seven structures in Iowa having in common the same type of cracking and the same cementitious material in the mortar. An unanswered question, until recently, was why the cementitious material reacted as it did in Iowa whereas there was no report of similar behavior in Wisconsin. Mr. Wuerpel has provided evidence that crossing state lines does not change the properties of materials. The latest report is that ten of these cases have been recognized in Wisconsin.

Mr. Reitz presents a very interesting example of expansion. Open-hearth rather than blast-furnace slag would be suspected from his description of the material.

Mr. Anderegg very properly calls attention to the uncertain and frequently unsatisfactory behavior of pointing mortars, and makes a case for some controlled expansion in these mortars. Instances have been noted where spalling and chipping of the edges of stone in contact with mortar bed joints has occurred, and reports from England have ascribed spalling of brick faces to repointing with hard mortars. What effect would the use of an expanding mortar have on these behaviors?

Mr. Connor appears to be asking for generalizations and extrapolations that go far beyond available data. Counting both personal inspections and the study of competent descriptions, with or without photographs, the author has information concerning probably less than 0.01 per cent of all the masonry structures in the United States. To express an opinion on the condition of the 99.99 per cent residue and offer estimates on the relative frequency of occurrence of various causes of cracking, where cracking has occurred, requires a degree of temerity beyond that possessed by this author. This much can be said: All strain-gage measurements made at the National Bureau of Standards on brick-mortar assemblages of commercial size have confirmed the findings of Davis and Troxell, which was that increase, not decrease, in height occurs. The change-of-length data presented in Fig. 1 where a sound mortar was used, are typical for piers laid with such mortars. As a matter of interest, the field evidence for Mr. Connor's "separation cracking" has been inspected by certain investigators who later discussed this matter with the author. Their considered judgment is that the observed effects resulted from workmanship, and not from shrinkage of mortar. Mr. Connor should understand that there are many causes for cracking in brick masonry. The list of ten causes given in the first three paragraphs of the current paper will probably be added to from time to time.

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[10] L. S. Wells, W. F. Clarke, and E. M. Levin, "Expansion Characteristics of Hydrated Limes and the Development of an Autoclave Test for Soundness," *Journal of Research*, Nat. Bureau of Standards, Vol. 41, Sept., 1948, pp. 179–204 (RP1917).

Mr. Webb's explanation of the background of the quotation nicely clears up what had appeared to be a difference of opinion. His observations on the effect of temperatures of burning on rate of hydration are in almost perfect agreement with the findings of research workers in the United States. The commercial practicability of obtaining the desired results by control of temperature of burning is, however, questioned. Mr. Webb's conclusion that severe early expansion results from free calcium oxide is accepted. The very few examples of such action identified in the United States had occurred where lump lime had been slaked on the job. The action of soluble sulfates is, as indicated by Mr. Webb, a factor in expansion of mortar. Additions of calcium, magnesium, and sodium sulfates to certain piers built as a part of efflorescence studies caused very large and sudden expansion after a few months. No field examples have been observed or identified to date.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON PLASTICS TESTING—PRESENT AND FUTURE

Committee D-20 on Plastics was the sponsor of this Symposium, the purpose of which was to examine some procedures used for determining certain physical and physical-chemical properties of plastics. The Symposium was held on June 26, 1952, in New York, N. Y., at the Fifty-fifth Annual Meeting of the Society at the Twenty-seventh Session.

The following papers were presented:

Introductory Remarks—C. R. Stock
The Measurement and Significance of the Mechanical Strength Properties of Plastics—C. Howard Adams
Measurement of the Effect of Temperature on Some Physical Properties of Plastics—J. P. Tordella, A. C. Webber, and E. B. Cooper
Measurement of Color, Gloss, and Haze—H. K. Hammond, III, and G. W. Ingle
The Effects of Molding Conditions upon the Permanence of Plastics—J. L. Williams and J. W. Mighton
An Improved Fadeometer—Ladislav Boor and Seymour L. Tucker
Residual Stresses in Phenolic Plastics—L. E. Welch and H. M. Quackenbos, Jr.
Conditioning and Weathering of Adhesives and Plastics—F. W. Reinhart (presented at the Symposium on Conditioning and Weathering)

These papers together with their discussion, with the exception of the Boor and Tucker paper, have been issued as *ASTM Special Technical Publication No. 132*, entitled "Symposium on Plastics Testing—Present and Future." The Boor and Tucker paper appears in ASTM BULLETIN, No. 189, April, 1953, p. 38 (TP 44).

A GENERAL ANALYTIC SOLUTION FOR MOHR'S ENVELOPE*

By Glenn Balmer[1]

Synopsis

Parametric equations are derived for Mohr's envelope in terms of the principal stresses as parameters. The equations are perfectly general and apply to a linear or a curvilinear envelope. No vindication is advanced to justify the use of Mohr's theory as an analysis of failure; however, if Mohr's criterion is applied, the parametric equations provide an analytic approach to the solution.

Judgment must be exercised in deciding upon the nature of the function which best describes the experimental data. An example is presented using a linear equation for soil analysis. Confidence limits are derived as a measure of the reliability of the fitted line. Further, an example is given using a curvilinear relation for the failure of concrete specimens. The best fit in the least squares sense is obtained for the function selected. Criteria other than least squares can be used for fitting these curves if desired.

Notation

The statistical notation in this paper is similar to the notation in "Methods of Correlation Analysis"[2] by Ezekiel:

S_1 = major principal stress, axial stress, at failure in psi,

S_3 = minor principal stress, lateral or circumferential stress, at failure in psi,

X = normal stress at failure in psi,

Y = shearing stress at failure in psi,

s_1, s_3, x, y = stresses at failure in psi in terms of departures from their arithmetic means,

ϕ = inclination of the envelope to Mohr's circles, angle of internal friction, in degrees,

α = angle of failure in degrees,

$\frac{dY}{dX} = \tan \phi$ = slope of Mohr's envelope,

$\frac{\partial S_1}{\partial S_3}$ = partial derivative of S_1 with respect to S_3, slope of the axial-lateral stress curve,

ΔS_1 = axial stress difference in psi,

ΔS_3 = lateral stress difference in psi,

$\frac{\Delta S_1}{\Delta S_3}$ = derivative expressed in terms of finite increments,

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* Presented at the Fifty-fifth Annual Meeting of the Society, June 23–27, 1952.

[1] Physicist, Bureau of Reclamation, Denver, Colo.

[2] Mordecai Ezekiel, "Methods of Correlation Analysis," second edition, John Wiley and Sons, Inc., New York, N. Y. (1941).

n = number of observations,
Σ = summation of n items,
C = unit cohesive strength in psi,
A, B = arbitrary symbols defined by Eq 17 and 18
σ = standard deviation in psi,
$\sigma_{Y'_{yx}}$ = standard error of the estimated shearing strength for the regression line of Y on X in psi,
S_{yx} = unbiased estimate of the standard error of estimate in psi,
M_x = arithmetic mean value of X in psi,
$a, b, c,$ = arbitrary constants.

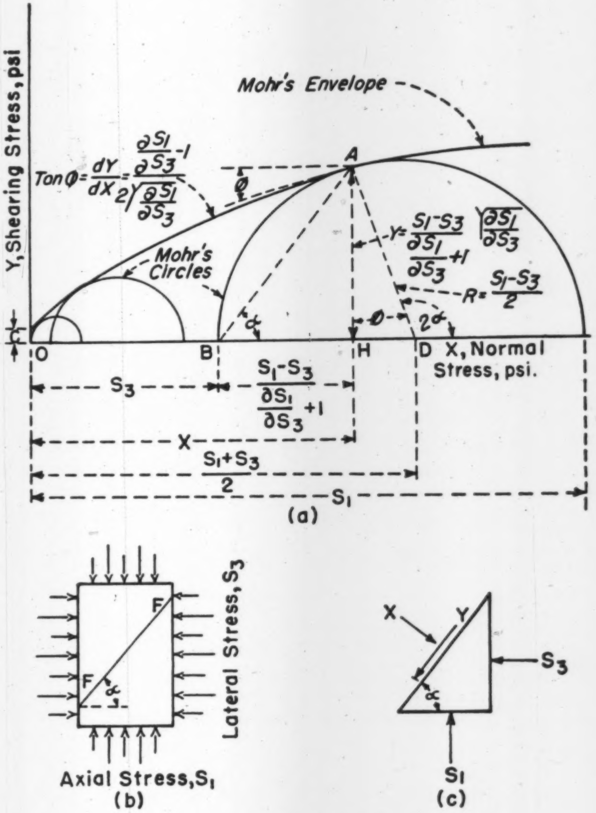
Y, Shearing Stress, psi
Mohr's Envelope
A
$\text{Tan}\,\phi = \frac{dY}{dX} = \frac{\frac{\partial S_1}{\partial S_3} - 1}{2\sqrt{\frac{\partial S_1}{\partial S_3}}}$
ϕ
Mohr's Circles
$Y = \frac{S_1 - S_3}{\frac{\partial S_1}{\partial S_3} + 1}\sqrt{\frac{\partial S_1}{\partial S_3}}$
$R = \frac{S_1 - S_3}{2}$
α
ϕ
2α
C
O
B
H
D
X, Normal Stress, psi.
S_3
$\frac{S_1 - S_3}{\frac{\partial S_1}{\partial S_3} + 1}$
X
$\frac{S_1 + S_3}{2}$
S_1
(a)
F
F
α
Lateral Stress, S_3
Axial Stress, S_1
(b)
X
Y
S_3
α
S_1
(c)

FIG. 1.—Mohr's Diagram.

DEVELOPMENT OF PARAMETRIC EQUATIONS

According to Mohr's theory of failure,[3] the coordinates for the center of a Mohr's circle are $\left(\frac{S_1 + S_3}{2}, O\right)$, and the radius is $\frac{S_1 - S_3}{2}$ where S_1 is the major principal stress and S_3 the minor principal stress at failure. In the analysis of triaxial compression tests of cylinders stressed axially and circumferentially, the cylinders are treated as though they were subjected to biaxial combined stress in accord with Mohr's assumption that the intermediate principal stress has no influence on failure. From this center and radius, the equation for a system of Mohr's circles can be written

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[3] Karl Terzaghi and Ralph B. Peck, "Soil Mechanics in Engineering Practice," Article 16, John Wiley and Sons, Inc., New York, N. Y. (1948).

$$\left(X - \frac{S_1 + S_3}{2}\right)^2 + Y^2 = \left(\frac{S_1 - S_3}{2}\right)^2 \quad (1)$$

where X represents the normal stress and Y the shearing stress on the plane of failure. This equation can be thought of as representing a system of Mohr's circles in terms of the two parameters S_1 and S_3.

If the partial derivative of S_1 with respect to S_3 is determined and solved for X, the following equation is obtained

$$X = S_3 + \frac{S_1 - S_3}{\dfrac{\partial S_1}{\partial S_3} + 1} \quad\ldots\ldots\ldots (2)$$

If Eq 2 is substituted in Eq 1 and solved for Y, the result is

$$Y = \frac{S_1 - S_3}{\dfrac{\partial S_1}{\partial S_3} + 1}\sqrt{\frac{\partial S_1}{\partial S_3}} \quad\ldots\ldots\ldots (3)$$

Equations 2 and 3 are the parametric equations of Mohr's envelope expressed in terms of S_1, S_3, and $\dfrac{\partial S_1}{\partial S_3}$, the axial stress, the lateral stress, and the slope of the curve relating these two stresses. They can be interpreted graphically as shown in Fig. 1. The envelope below the X axis can be obtained by using a negative sign on the radical in Eq 3. X is the normal stress consisting of two components, S_3 (the distance *OB*) and $\dfrac{S_1 - S_3}{\dfrac{\partial S_1}{\partial S_3} + 1}$ (the distance *BH* or that portion of the normal stress which falls within Mohr's circle). This latter quantity is somewhat similar to the shearing stress, Y, in that both quantities are expressed as a fractional part of the diameter of Mohr's circle, $S_1 - S_3$, the stress difference. This stress difference has been treated as one of the variables by certain authors. It is also the unidimensional load which must be added to the hydrostatic load to give the total axial load.

From Eq 2 and 3 the ratio of

$$\frac{Y}{X - S_3} = \sqrt{\frac{\partial S_1}{\partial S_3}} \quad\ldots\ldots\ldots (4)$$

It can be seen from triangle *AHB* in Fig. 1(*a*) that this ratio is the ratio of *HA* to *BH* which is equal to tan α where α is the angle of failure; therefore,

$$\tan \alpha = \sqrt{\frac{\partial S_1}{\partial S_3}} \quad\ldots\ldots\ldots (5)$$

It can also be noted that triangle *AHB* is similar to the triangle in Fig. 1(*c*); hence, *AB* theoretically represents the plane of failure of the specimen. From Fig. 1 with a curved envelope there is a varying angle of internal friction, ϕ, and a varying angle of failure, α.

As can be seen from triangle *AHD*

$$2\alpha = \phi + 90° \quad\ldots\ldots\ldots (6)$$

where ϕ is the inclination of Mohr's envelope, also known as the angle of internal friction. From Eqs 5 and 6

$$\frac{dY}{dX} = \tan \phi = \frac{\dfrac{\partial S_1}{\partial S_3} - 1}{2\sqrt{\dfrac{\partial S_1}{\partial S_3}}} \quad\ldots\ldots (7)$$

with $\dfrac{dY}{dX} = \tan \phi$ symbolizing the slope of Mohr's envelope. Clearly the slope of the axial-lateral stress curve, $\dfrac{\partial S_1}{\partial S_3}$, and the slope of Mohr's envelope, $\dfrac{dY}{dX}$, are related.

APPLICATION FOR A LINEAR ENVELOPE

In applying the above equations to a particular problem, there are two approaches available. One approach is to select a function which describes Mohr's envelope and by a method of curve fitting, fit this function as the envelope. From the constants determined, the relationship is established between the axial stress and the lateral stress. The other approach is to select a function which describes the relation between the axial stress and the lateral stress, and by a method of curve fitting, fit this function to the experimental data. The arbitrary constants thus determined can then be used to express the equations for Mohr's envelope. In either case judgment is involved in selecting a formula which adequately describes the experimental data and is still simple enough for the mathematical operations to be feasible. A number of such empirical formulas are discussed by Lipka.[4]

TABLE I.—TRIAXIAL COMPRESSION DATA FOR SOIL[a]

Lateral Stress, psi	Axial Stress, psi	Sum
S_3	S_1	$S_1 + S_3$
10.6	59.1	69.7
18.9	81.9	100.8
30.0	129.9	159.9
40.4	152.9	193.3
78.2	294.1	372.3
178.1	717.9	896.0[b]

$n = 5$

[a] Corrected for pore pressure.

[b] Check point.

As an example, using the first approach, assume with C and ϕ constant

$$Y = C + X \tan \phi \quad \ldots\ldots\ldots (8)$$

adequately fits Mohr's circles as an envelope for the data given in Table I, graphically shown in Fig. 2. C is the unit cohesive strength of the material, and the other symbols have been defined earlier in this paper.

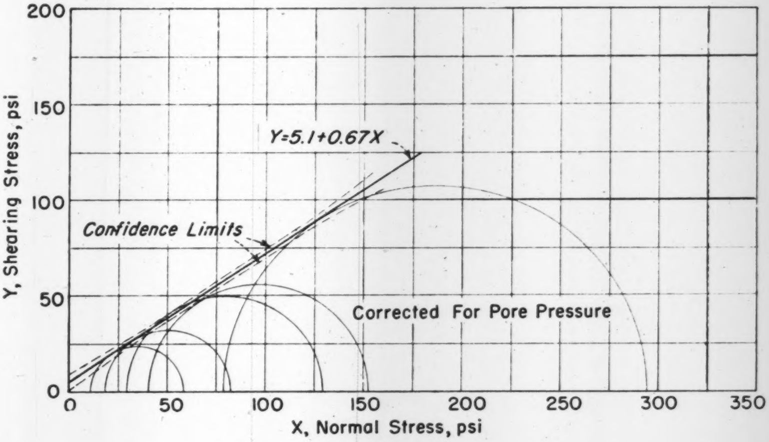

FIG. 2.—Mohr's Diagram for Soil.

From the theory of least squares, Chapter V of Ezekiel's book,[2] the most probable values of tan ϕ and C are given by

$$\tan \phi = \frac{n\Sigma XY - \Sigma X \Sigma Y}{n\Sigma X^2 - (\Sigma X)^2} \quad \ldots\ldots (9)$$

and

$$C = \frac{\Sigma Y - \tan \phi \, \Sigma X}{n} \quad \ldots\ldots (10)$$

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[4] Joseph Lipka, "Graphical and Mechanical Computation," John Wiley and Sons, Inc., New York, N. Y. (1918)

in which n is the number of tests, and Σ denotes summation from 1 to n inclusive.

Since experimental data are compiled in terms of S_1 and S_3 rather than in terms of X and Y, it is desirable to transform these equations so that they can be solved directly from experimental data.

TABLE II.—COMPUTATION OF TANGENT TO MOHR'S CIRCLES FOR THE DATA OF TABLE I.

	Item	S_3	S_1	$S_1 + S_3$
	Sums (from Table I)	178.1	717.9	896.0[a]
S_3	Sum of products (S_1, S_3)	9 116.97	35 247.15	44 364.12[a]
	Product of sums divided by n	6 343.92	25 571.60	31 915.52
	Sum of products (s_1, s_3)	2 773.05	9 675.55	12 448.60[a]
S_1	Sum of products (S_1, S_1)		136 947.65	172 194.80[a]
	Product of sums divided by n		103 076.08	128 647.68
	Sum of products (s_1, s_3)		33 871.57	43 547.12[a]

$n = 5$

[a] Check points.

$$A^2 = \frac{33\,871.57}{2\,773.05} = 12.215 \text{ (Eq 17)},$$

$$A = 3.495, \text{ and } \sqrt{A} = 1.869.$$

$$\tan\phi = \frac{3.495-1}{2(1.869)} = 0.67 \text{ (Eq 20)},$$

$$\phi = 33°50', \alpha = 61°55' \text{ (Eq 6)}.$$

$$C = \frac{717.9 - 3.495(178.1)}{2(5)(1.869)} = 5.1 \text{ (Eq 21)},$$

$$Y = 5.1 + 0.67\,X \text{ (Eq 8)}.$$

$$B^2 = \frac{9\,675.55}{2\,773.05} = 3.489 \text{ (Eq 18)},$$

$$B^4 = 12.173 \text{ and } B = 1.868.$$

$$\sigma_{s_3}^{\,2} = \frac{2773.05}{5} = 554.61 \text{ (Eq 15)}.$$

$$S_1 = 19.1 + 3.50\,S_3 \text{ (Eq 23)}.$$

From Eq 7

$$\sqrt{\frac{\partial S_1}{\partial S_3}} = \tan\phi + \sqrt{1 + \tan^2\phi} \quad \ldots (11)$$

The positive sign shall be used on both radicals, since a negative sign on the first radical yields the branch of the envelope below the X axis, and a negative sign on the second radical interchanges the subscripts on S_1 and S_3.

From Eq 2, 3, and 11

$$X = \tfrac{1}{2}[S_1(1 - \sin\phi) + S_3(1 + \sin\phi)] \quad \ldots (12)$$

and

$$Y = \frac{S_1 - S_3}{2}\cos\phi \quad \ldots\ldots\ldots (13)$$

In statistical notation

$$n\Sigma\, s_1^2 = n^2\sigma_{s_1}^{\,2} = n\Sigma\, S_1^2 - (\Sigma\, S_1)^2, \quad \ldots\ldots (14)$$

$$n\Sigma\, s_3^2 = n^2\sigma_{s_1}^{\,2} = n\Sigma\, S_3^2 - (\Sigma\, S_3)^2, \quad \ldots\ldots (15)$$

and

$$n\Sigma\, s_1 s_3 = n\Sigma\, S_1 S_3 - \Sigma\, S_1\, \Sigma\, S_3 \quad \ldots (16)$$

which, in effect, translates the origin to the arithmetic means. The capital letters are the old variables and the lower case letters are the new variables which indicate that the origin has been translated to the means.

Further, define

$$A^2 = \frac{\Sigma s_1^2}{\Sigma s_3^2} \quad \ldots\ldots\ldots (17)$$

and

$$B^2 = \frac{\Sigma s_1 s_3}{\Sigma s_3^2} \quad \ldots\ldots\ldots (18)$$

Substituting Eqs 12 and 13 in Eq 9, simplifying with the aid of Eq 14 through 18, and solving for $\sin\phi$, we find

$$\sin\phi = \frac{A - 1}{A + 1} \quad \ldots\ldots\ldots (19)$$

from which it is deduced that

$$\tan\phi = \frac{A - 1}{2\sqrt{A}} \quad \ldots\ldots\ldots (20)$$

To obtain an expression for C in terms of major and minor stresses, Eqs 12, 13, and 20 are substituted in Eq 10, and it is found that

$$C = \frac{\Sigma S_1 - A\Sigma S_3}{2n\sqrt{A}} \quad \ldots\ldots\ldots (21)$$

The values of tan ϕ and C are computed in Table II for the data given in Table I; hence, the equation for Mohr's envelope is determined. Mohr's diagram is shown in Fig. 2 for these data. Conclusions from statistical analysis on a small number of cases are not as reliable as for a large number of cases; however, the data of Table I will serve to illustrate the application of the theory of this paper.

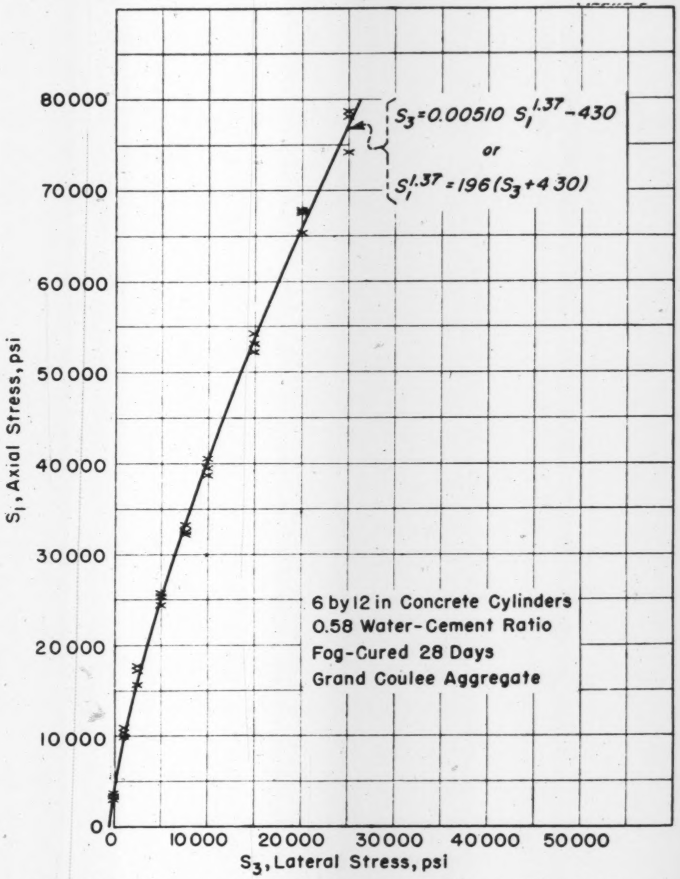

FIG. 3.—Relation of Axial Stress to Lateral Stress at Failure in Triaxial Compression Tests of Concrete.

By eliminating X and Y from Eq 8, 12, and 13, there we obtain

$$S_1 = \frac{2C \cos \phi}{1 - \sin \phi} + \frac{1 + \sin \phi}{1 - \sin \phi} S_3 \quad \ldots (22)$$

which is the relationship between the principal stresses. This equation can be reduced to

$$S_1 = 2C \sqrt{A} + AS_3 \ldots\ldots (23)$$

for the least squares criterion employed in this section. The above equation is computed in Table II as determined by the least squares solution of Eq 8. A graph of this equation, the axial-lateral stress relation, can be drawn for these data similar to Fig. 3, except that the curve is linear for this analysis.

CONFIDENCE LIMITS

After the "best fitting" straight line has been determined in the least squares sense as the envelope to Mohr's circles for these test data, it is desirable to determine confidence limits or a statistical estimate of the range of deviation that is to be expected for this line. To accomplish this a formula for the standard error of the estimated shearing stress, $\sigma_{Y'}$, is desired in terms of S_1 and S_3 for any departure, x, from the mean of the normal stress.

TABLE III.—COMPUTATION OF CONFIDENCE LIMITS,

$$2\sigma_{Y'_{yx}} = \sqrt{\frac{A - B^2}{n - 2}\left[2\sigma_{s_3}{}^2 + \frac{(A + 1)^2\, x^2}{A(A + B^2)}\right]} \text{ (Eq 33)},$$

for $Y = 5.1 + 0.67\ X$ (Eq 8).

From the values in Table II

$$2\sigma_{Y'_{yx}} = \sqrt{2.2184 + 0.00166\ x^2} \text{ (Eq 33)}$$

and $M_X = \dfrac{717.9 + (3.495)(178.1)}{5(4.495)} = 59.6$ (Eq 34);

hence, $x = X - 59.6$ (Eq 25).

A tabulation is given below to facilitate plotting these confidence limits.

x	X	Y	$(2\sigma_{Y'})^2$	$2\sigma_{Y'}$	$Y + 2\sigma_{Y'}$	$Y - 2\sigma_{Y'}$
−40	19.6	18.2	4.8744	2.21	20.4	16.0
−20	39.6	31.6	2.8824	1.70	33.3	29.9
0	59.6	45.0	2.2184	1.49	46.5	43.5
20	79.6	58.4	2.8824	1.70	60.1	56.7
40	99.6	71.8	4.8744	2.21	74.0	69.6
60	119.6	85.2	8.1944	2.86	88.1	82.3
80	139.6	98.6	12.8424	3.58	102.2	95.0

The standard error of Y', for any particular value of x, is given by the formula (page 316 and Appendix 4 of Ezekiel's book[2])

$$\sigma_{Y'_{yx}} = \sqrt{\sigma^2_{M_{Y'}} + \sigma^2_{(\tan\phi)_{yx}}\, x^2} \quad \text{....(24)}$$

where

$$x = X - M_x, \quad \text{..........(25)}$$

$$\sigma^2_{M_{Y'}} = \frac{\bar{S}^2_{yx}}{n}, \quad \text{..........(26)}$$

and

$$\sigma^2_{(\tan\phi)_{yx}} = \frac{\bar{S}^2_{yx}}{n\sigma^2_x}. \quad \text{.........(27)}$$

Furthermore,

$$\bar{S}^2_{yx} = \frac{n\,\sigma^2_y}{n - 2}(1 - r^2) \quad \text{......(28)}$$

with

$$r = \frac{\Sigma(xy)}{n\sigma_x\sigma_y}. \quad \text{...........(29)}$$

By reference to Eq 9, it can be seen that

$$r = \frac{\sigma_x}{\sigma_y}\tan\phi. \quad \text{...........(30)}$$

After application of the above formulas to Eq 24, it is found that

$$\sigma^2_{Y'_{yx}} = \frac{1}{n - 2}\left[\frac{\sigma^2_y}{\sigma^2_x} - \tan^2\phi\right](\sigma^2_x + x^2) \quad \text{..(31)}$$

Since experimental data are tabulated as values of S_1 and S_3, Eq 31 is more readily adapted to computation in the form

$$\sigma^2_{Y'_{yx}} = \frac{A - B^2}{2(n - 2)}\left[\sigma^2_{s_3} + \frac{(A + 1)^2 x^2}{2A(A + B^2)}\right] \quad \text{...(32)}$$

The development of this equation is shown in the appendix.

According to the theory of the normal error curve, a range of deviation of one standard error from the mean yields a probability of 68 chances in 100 of including all possible cases under consideration. The corresponding probability for two standard errors is 95 chances in 100 and for three standard errors is 99 chances in 100 when applied to large samples. For samples under 30 the probabilities are somewhat reduced. Accordingly, depending upon the degree of certainty desired, a multiple value of Eq 32 can be used in determining confidence limits. In application to tests of physical properties, it is not uncommon to use a range of deviation of two standard errors, thus

$$2\sigma_{Y'_{yx}} = \sqrt{\frac{A - B^2}{n - 2}\left[2\sigma_{S3}^{\,2} + \frac{(A + 1)^2 x^2}{A(A + B^2)}\right]} \ldots (33)$$

By means of Eq 12 and 19, it is found that

$$M_x = \frac{\Sigma X}{n} = \frac{1}{n(A + 1)}\,(\Sigma S_1 + A\Sigma S_3) \ldots (34)$$

Confidence limits for Eq 8 are computed in Table III and shown graphically in Fig. 2. They provide a statistical estimate of the range of deviation that is to be expected for the line of Eq 8 determined by the method of least squares. They provide a measure of reliability of this line, a measure of the probable variation of the line.

TABLE IV.—TEST DATA FOR 6- BY 12-IN. CONCRETE CYLINDERS CAST WITH AN 0.58 WATER-CEMENT RATIO AND FOG-CURED 28 DAYS.

Lateral Stress, psi	Axial Stress, psi	Lateral Stress Difference	Axial Stress Difference	Difference Ratio	Log of Ratio	Log of Axial Stress	Sum
S_3	S_1	ΔS_3	ΔS_1	$\frac{\Delta S_1}{\Delta S_3}$	$\log \frac{\Delta S_1}{\Delta S_3}$	$\log S_1$	$\log \frac{\Delta S_1}{\Delta S_3} + \log S_1$
0	3 460	1 000	6 490	6.490	0.81224	3.53908	4.35132
0	3 510	1 000	6 590	6.590	0.81889	3.54531	4.36420
0	3 750	1 000	7 300	7.300	0.86332	3.57403	4.43735
1 000	9 950	1 500	6 010	4.007	0.60282	3.99782	4.60064
1 000	10 100	1 500	7 140	4.760	0.67761	4.00432	4.68193
1 000	11 050	1 500	6 670	4.447	0.64807	4.04336	4.69143
2 500	15 960	2 500	8 420	3.368	0.52737	4.20303	4.73040
2 500	17 240	2 500	8 000	3.200	0.50515	4.23654	4.74169
2 500	17 720	2 500	7 890	3.156	0.49914	4.24846	4.74760
5 000	24 380	2 500	7 900	3.160	0.49969	4.38703	4.88672
5 000	25 240	2 500	7 320	2.928	0.46657	4.40209	4.86866
5 000	25 610	2 500	7 570	3.028	0.48116	4.40841	4.88957
7 500	32 280	2 500	6 560	2.624	0.41896	4.50893	4.92789
7 500	32 560	2 500	7 000	2.800	0.44716	4.51268	4.95984
7 500	33 180	2 500	7 510	3.004	0.47770	4.52088	4.99858
10 000	38 840	5 000	13 370	2.674	0.42716	4.58928	5.01644
10 000	39 560	5 000	13 510	2.702	0.43169	4.59726	5.02895
10 000	40 690	5 000	13 610	2.722	0.43489	4.60949	5.04438
15 000	52 210	5 000	13 090	2.618	0.41797	4.71775	5.13572
15 000	53 070	5 000	14 460	2.892	0.46120	4.72485	5.18605
15 000	54 300	5 000	13 610	2.722	0.43489	4.73480	5.16969
20 000	65 300	5 000	8 960	1.792	0.25334	4.81491	5.06825
20 000	67 530	5 000	10 620	2.124	0.32715	4.82950	5.15665
20 000	67 910	5 000	10 860	2.172	0.33686	4.83193	5.16879
25 000	74 260						
25 000	78 150						
25 000	78 770						
					12.27100	104.58174	116.85274[a]

$n = 24$

[a] Check point.

If it is assumed from the second approach that Eq 22,

$$S_1 = \frac{2C\cos\phi}{1 - \sin\phi} + \frac{1 + \sin\phi}{1 - \sin\phi}S_3, \ldots (22)$$

represents the data of Table I with sufficient accuracy and if it is fitted to the data by the method of least squares instead of applying least squares to Eq 8, a slightly different solution is obtained

$$S_1 = 2CB + B^2S_3 \ldots\ldots\ldots (35)$$

This is the least squares solution of Eq 22, and transformation through application of Eq 12 and 13 yields

$$Y = C + X\tan\phi \ldots\ldots\ldots (8)$$

with

$$\tan\phi = \frac{B^2 - 1}{2B} \ldots\ldots\ldots (36)$$

and

$$C = \frac{\Sigma S_1 - B^2 \Sigma S_3}{2nB} \qquad \text{.........(37)}$$

This is the method applied by Smith and Brown[5] in determining the shearing strength of cement mortar. The difference in the two solutions is due to minimizing different quantities in the application of the theory of least squares.

TABLE V.—COMPUTATION OF c FOR THE DATA OF TABLE IV.

	Item	$\log \frac{\Delta S_1}{\Delta S_3}$	$\log S_1$	$\log \frac{\Delta S_1}{\Delta S_3} + \log S_1$
	Sums (from Table IV)	12.27100	104.58174	116.85274[a]
$\log \frac{\Delta S_1}{\Delta S_3}$	Sum of products (S_1, S_3)	6.82235	52.10516	58.92751[a]
	Product of sums divided by n	6.27406	53.47177	59.74583
	Sum of products (s_1, s_3)	0.54829	−1.36661	−0.81832[a]
$\log S_1$	Sum of products (S_1, S_3)		459.38701	511.49217[a]
	Product of sums divided by n		455.72251	509.19429
	Sum of products (s_1, s_3)		3.66450	2.29788[a]

$n = 24$

[a] Check points.

Taking values from the above table, we have

$$-(c-1) = \frac{-1.36661}{3.66450} = -0.373;$$

hence, $c = 1.37$.

The standard error of c is

$$\sigma_c = \sqrt{\frac{1}{22}\left[\frac{0.54829}{3.66450} - \left(\frac{-1.36661}{3.66450}\right)^2\right]} = 0.022.$$

The selection of the method to use for a particular problem depends upon which method is best adapted to the problem or which is more readily applied to yield the desired quantities.

The formula,

$$\sigma^2_{S'_{s_1 s_3}} = \frac{A^2 - B^4}{n-2}\left(\sigma^2_{s_3} + s_3^2\right), \qquad \text{.....(38)}$$

can be used for computing confidence limits for Eq 35 in a manner similar to the use of Eq 32 in computing confidence limits for Eq 8.

APPLICATION FOR A CURVED ENVELOPE

As an illustration for a curved envelope consider

$$S_3 = bS_1^c + a, \qquad \text{..........(39)}$$

a function which it is assumed adequately relates the axial stress to the lateral stress for the experimental data on the strength of concrete specimens given in the first two columns of Table IV. Thus, the second approach is being used in this example. Arbitrary constants, a, b, and c, are determined from the data by the method of least squares. To accomplish this the equation can be considered in two steps. The first step is to evaluate c. If the derivative of Eq 39 is approximated by using finite increments in order to apply it to discreet data,

$$\frac{\Delta S_1}{\Delta S_3} = \frac{1}{bcS_1^{c-1}} \qquad \text{...........(40)}$$

TABLE VI.—COMPUTATIONS FOR THE DATA OF TABLE IV.

Lateral Stress $S_3 \times (10^{-2})$	Axial Stress to a Power $S_1^{1.37} \times (10^{-2})$	Sum $[S_3 + S_1^{1.37}] \times (10^{-2})$
0	706	706
0	720	720
0	788	788
10	2 999	3 009
10	3 061	3 071
10	3 463	3 473
25	5 730	5 755
25	6 369	6 394
25	6 613	6 638
50	10 238	10 288
50	10 737	10 787
50	10 953	11 003
75	15 039	15 114
75	15 219	15 294
75	15 617	15 692
100	19 378	19 478
100	19 872	19 972
100	20 654	20 754
150	29 061	29 211
150	29 719	29 869
150	30 668	30 818
200	39 485	39 685
200	41 345	41 545
200	41 662	41 862
250	47 090	47 340
250	50 502	50 752
250	51 051	51 301
2580	528 739	531 319[a]

$n = 27$

[a] Check point.

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[5] Frederick C. Smith and Robert Q. Brown, "The Shearing Strength of Cement Mortar," *Bulletin No. 106*, February, 1941, Engineering Experiment Station, University of Washington, Seattle, Wash.

TABLE VII.—COMPUTATION OF a AND b FOR DATA OF TABLE IV.

	Item	S_3 $\times(10^{-7})$	$S_1^{1.37}$ $\times(10^{-7})$	$[S_3+S_1^{1.37}]$ $\times(10^{-7})$
	Sums (from Table VI)	0.02580	5.28739	5.31319[a]
S_3	Sum of products (S_1, S_3)	432	86 667	87 098[a]
	Product of sums divided by n	247	50 524	50 770
	Sum of products (s_1, s_3)	185	36 143	36 328[a]
$S_1^{1.37}$	Sum of products (S_1, S_3)		17 434 470	17 521 137[a]
	Product of sums divided by n		10 354 257	10 404 781
	Sum of products (s_1, s_3)		7 080 213	7 116 356[a]

$n = 27$

[a] Check points.

From least squares theory, by applying values from the above table,

$$b = \frac{36{,}143 \times 10^7}{7\ 080\ 213 \times 10^7} = 0.00510.$$

The standard error of b is

$$\sigma_b = \sqrt{\frac{1}{25}\left[\frac{185 \times 10^7}{7\ 080\ 213 \times 10^7} - \left(\frac{36{,}143 \times 10^7}{7\ 080\ 213 \times 10^7}\right)^2\right]} = 0.000053$$

and

$$a = \frac{\Sigma S_3 - b\Sigma S_1^{1.37}}{n} = \frac{0.02580 \times 10^7 - 0.00510\,(5.28739 \times 10^7)}{27} = -432.$$

Therefore, Eq 39 becomes

$$S_3 = 0.00510\, S_1^{1.37} - 430.$$

In logarithmic form

$$\log\frac{\Delta S_1}{\Delta S_3} = -\log\,(bc) - (c-1)\log S_1 \ldots (41)$$

Eq 41 is in linear form if $\log\dfrac{\Delta S_1}{\Delta S_3}$ and $\log S_1$ are considered the variables with $\log\,(bc)$ and $(c-1)$ the arbitrary constants. Now the numerical value of c can be determined by the conventional method of least squares. This value is computed in Tables IV and V.

Since c is known, the method of least squares can be applied to Eq. 39 to determine a and b. This computation is illustrated in Tables VI and VII. Hence, the constants a, b, and c are determined. The curve thus determined is shown in Fig. 3.

By substitution of Eqs 39 and 40, using $\dfrac{\Delta S_1}{\Delta S_3}$ equal to $\dfrac{\partial S_1}{\partial S_3}$ in Eqs 2 and 3, S_3 is eliminated, and the results are that

$$X = \frac{b(c+1)S_1^c}{1 + bcS_1^{c-1}} + a \ldots\ldots (42)$$

and

$$Y = \frac{S_1 - a - bS_1^c}{1 + bcS_1^{c-1}}\sqrt{bcS_1^{c-1}}, \ldots (43)$$

the parametric equations of Mohr's envelope in terms of one parameter, S_1, when S_1 and S_3 obey Eq 39.

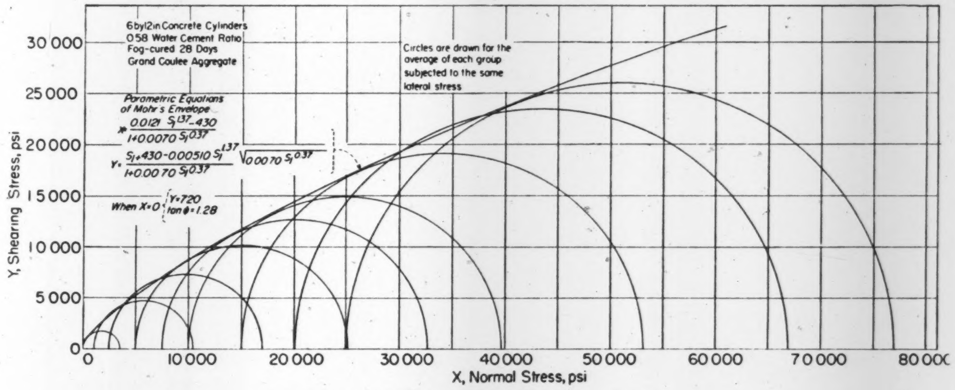

FIG. 4.—Mohr's Diagram for Concrete.

From Eq 7 and 40

$$\frac{dY}{dX} = \frac{1 - bcS_1^{c-1}}{2\sqrt{bcS_1^{c-1}}}, \ldots\ldots\ldots (44)$$

the slope of Mohr's envelope in terms of the parameter, S_1, when Eq 39 defines the relationship between S_1 and S_3. Mohr's diagram for these data is given in Fig. 4, in which circles are drawn for the average axial pressure of each group subjected to the same lateral pressure.

Confidence limits can also be computed for Eq 39, if desired, by considering this equation linear in the two variables S_3 and S_1^c. To simplify notation let $S_1^c = Z$; then

$$\sigma^{2\prime}_{S_{s_1 z}} = \frac{1}{(n-2)}\left[\frac{\sigma^2_{s_3}}{\sigma^2_z} - \frac{(\Sigma s_3 z)^2}{n^2\sigma^4_z}\right](\sigma^2_z + z^2). \quad (45)$$

CONCLUSIONS

Certain engineering materials produce definite evidence that Mohr's envelope is a curve rather than a straight line when the experimental data for such materials are analyzed by Mohr's theory. The parametric equations for Mohr's envelope developed in this paper are general and can be applied either to a curve or a straight line. Where there are sufficient data which show marked curvature, the additional work necessary in analyzing the data as a curve will more closely produce the true values which characterize the material. In general a curvilinear analysis will yield a smaller unit cohesive strength than a linear analysis—believed to be nearer the true value. The inclination of Mohr's envelope, ϕ, also known as the angle of internal friction, will vary for a curved envelope with high values in the lower ranges and low values in the higher ranges. This is probably a better analysis of the values of this angle than a constant value obtained by a linear analysis. Corresponding to the variation in ϕ, the angle of failure, α, will be variable for a nonlinear analysis. It will be interesting to observe whether experimental evidence substantiates this theoretical conclusion.

Usually a linear analysis is simpler than a curvilinear analysis; consequently, it is preferable for those data which can be accurately described by a straight line.

While it has been the purpose of this paper to present an analytic approach as the solution for Mohr's envelope, meager experimental data in some cases may not justify an extensive analysis. In such cases a curve drawn smoothly for the data may produce results as accurate as the data warrant.

Even though least squares theory has been applied in the analyses in this paper, the parametric equations for Mohr's envelope are not restricted to least squares theory. Curves can be fitted by the method of moments of areas, method of moments of ordinates, or some other curve fitting method.

Acknowledgment:

Grateful acknowledgment is made to Douglas McHenry for his supervision and valuable suggestions in the solution of this problem.

APPENDIX

DERIVATION OF EQUATION 32

This appendix is added to provide the details of the development of Eq 32 from Eq 31.

Analogous to Eq 14 and 15

$$n^2\sigma_y^2 = n\Sigma\, Y^2 - (\Sigma\, Y)^2 \ldots\ldots\ldots (46)$$

Substitution of the expression for Y given in Eq 13 in Eq 46, gives

$$n^2\sigma_y^2 = \frac{\cos^2\phi}{4}[n\Sigma S_1^2 - (\Sigma S_1)^2 - 2n\Sigma S_1 S_3$$

$$+ 2\Sigma S_1\Sigma S_3 + n\Sigma S_3^2 - (\Sigma S_3)^2] \ldots (47)$$

Dividing the terms within the brackets of Eq 47 by $n^2\sigma_{s_3}^2$, applying Eq 14 through 18, and replacing $\cos\phi$ by its value in terms of A defined by Eq 19, we get

$$n^2\sigma_y^2 = \frac{A}{(A+1)^2}(A^2 - 2B^2 + 1)n^2\sigma_{s_3}^2 \ldots (48)$$

Similar to Eq 14, 15, and 46

$$n^2\sigma_x^2 = n\Sigma\, X^2 - (\Sigma\, X)^2 \ldots\ldots\ldots (49)$$

Replacement of X in the above equation by the expression given in Eq 12, yields

$$n^2\sigma_x^2 = \tfrac{1}{4}\{[n\Sigma S_1^2 - (\Sigma S_1)^2](1 - \sin\phi)^2$$

$$+ 2[n\Sigma S_1 S_3 - \Sigma S_1\Sigma S_3](1 - \sin^2\phi)$$

$$+ [n\Sigma S_3^2 - (\Sigma S_3)^2](1 + \sin\phi)^2\} \ldots\ldots (50)$$

Dividing the terms within the braces of the above equation by $n^2\sigma_{s_3}^2$, applying Eq 14 through 18, and expressing $\sin\phi$ in terms of A from Eq 19, we obtain

$$n^2\sigma_x^2 = \frac{2A(A + B^2)}{(A+1)^2}\, n^2\sigma_{s_3}^2 \ldots\ldots (51)$$

If Eq 48 is divided by Eq 51,

$$\frac{\sigma_y^2}{\sigma_x^2} = \frac{A^2 - 2B^2 + 1}{2(A + B^2)} \ldots\ldots\ldots (52)$$

Substitution of Eqs 20, 51, and 52 in Eq 31 gives

$$\sigma^2_{Y'_{yx}} = \frac{A - B^2}{2(n-2)}\left[\sigma_{s_3}^2 + \frac{(A+1)^2 x^2}{2A(A + B^2)}\right] \ldots (32)$$

SUMMARY OF PROCEEDINGS OF SESSION ON FIFTY YEARS OF PAINT TESTING

A Session on Paint was sponsored by Committee D-1 on Paint, Varnish, Lacquer, and Related Materials at the Fourteenth Session of the Fifty-fifth Annual Meeting of the Society in New York, N. Y., June 24, 1952 in commemoration of the Fiftieth Anniversary of the establishment of the committee. The following papers review the work of individual subcommittees, giving major accomplishments, unsolved problems, and predictions of future developments.

Subcommittee II (Drying Oils)—F. Scofield
Subcommittee III (Bituminous Emulsions)—R. H. Cubberley
Subcommittee V (Volatile Hydrocarbon Solvents for Organic Protective Coatings)—N. T. Phelps and Stewart S. Kurtz, Jr.
Subcommittee VII (Accelerated Tests for Protective Coatings)—Roscoe H. Sawyer
Subcommittee VIII (Methods of Chemical Analysis of Paint Materials)—C. Y. Hopkins
Subcommittee IX (Varnish)—J. C. Weaver
Subcommittee X (Optical Properties)—Walter C. Granville
Subcommittee XI (Resins)—R. W. Stafford and C. F. Pickett
Subcommittee XII (Exterior Exposure Testing of Wood)—W. G. Vannoy
Subcommittee XIII (Shellac)—C. C. Hartman
Subcommittee XV—C. L. Crockett
Subcommittee XVI (Printing Ink)—A. C. Zettlemoyer
Subcommittee XVII (Flash Point)—Stewart S. Kurtz, Jr. and A. L. Brown
Subcommittee XVIII (Physical Properties of Materials)—Maynard R. Euverard
Subcommittee XXV (Cellulosic Coatings and Related Materials)—F. H. Lang
Subcommittee XXIX (The Protection of Iron and Steel)—Arnold J. Eickhoff

These papers together with discussions have been issued as *ASTM Special Technical Publication No. 147*, entitled "Fifty Years of Paint Testing."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON RECENT DEVELOPMENTS IN THE EVALUATION OF NATURAL RUBBER

The Twenty-ninth Session of the Fifty-fifth Annual Meeting of the Society in New York, N. Y., on June 26, 1952, was devoted to a Symposium dealing with the classification, evaluation, and testing of natural rubber. The Symposium was under the sponsorship of Subcommittee XII on Crude Natural Rubber of Committee D-11 on Rubber and Rubber-Like Materials.

The following papers were presented:

Introduction—Norman Bekkedahl
Technical Classification of Crude Natural Rubber—R. G. Newton
Quantitative Procedures for the Determination of Dirt in Crude Natural Rubber—R. P. Stock, C. O. Miserentino, C. B. McKeown, J. J. Hoesly, R. T. LaPort, and G. H. Wallace
Mooney Viscosity Measurements in Determining Processibility of Technically Classified Rubbers—Rolla H. Taylor and Alan G. Veith
Technically Classified Rubber—The Non-Rubber Content and the Measurement of Cure Rate—A. G. Veith
Vulcanization Characteristics of Natural Rubber—Robert D. Stiehler and Frank L. Roth
Preparation of a Standard Natural Rubber—E. M. McColm
Some Aspects of the Testing of Crude Rubber and Crude Rubber Compounds—L. V. Cooper and T. M. Kersker
Rubber Evaluations with Instron Testing Machine—S. D. Gehman and R. P. Clifford

These papers and discussions are issued as *ASTM Special Technical Publication No. 136*, entitled "Symposium on Recent Developments in the Evaluation of Natural Rubber."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON TESTING ADHESIVES FOR DURABILITY AND PERMANENCE

The papers in this Symposium were presented at the Twenty-fourth Session of the Fifty-fifth Annual Meeting of the Society held on June 26, 1952, in New York, N. Y. The durability and permanence of a variety of adhesives used in construction is of great importance. Committee D-14 on Adhesives arranged this Symposium in order to present field and laboratory test data that have been found for different kinds of adhesives.

The following papers were presented:

Introduction—G. W. Koehn
Effect of Specimen Structure in Permanence Tests on Wood Adhesives—Robert P. Hopkins
Glass Adhesives—Frank Moser
Current Investigations of the Durability of Woodworking Adhesives—Richard F. Blomquist
Non-destructive Determination of Mechanical Properties and Deterioration of Adhesives—Albert G. H. Dietz, Herman N. Bockstruck, and George Epstein
Field and Laboratory Tests for Durability and Permanence: Adhesives Belonging to the Rubber-Resins Systems—John F. Anderson and L. F. Fiedler

The papers together with their discussions are issued by *ASTM as Special Technical Publication No. 138*, entitled "Symposium on Testing Adhesives for Durability and Permanence."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON DIRECT SHEAR TESTING OF SOILS

At this Symposium, papers that discussed various phases of direct shear testing, and its usefulness or limitations, were presented. Under the sponsorship of Committee D-18 on Soils for Engineering Purposes, this Symposium was held at the Twenty-eighth Session of the Fifty-fifth Annual Meeting of the Society on June 26, 1952, in New York, N. Y.

The following papers were presented:

Introduction—Frederick J. Converse
The Place of the Direct Shear Test in Soil Mechanics—Donald M. Burmister
Use of Direct Shear Tests in Highway Design—Edward S. Barber
Use of Direct Shear Tests in Earth Work Projects Under Construction—R. R. Proctor
The Strength of Gravel in Direct Shear—R. G. Hennes
A Direct Shear Test with Drainage Control—Donald W. Taylor
The Use of the Direct Shear Testing Machine in Foundation Engineering Practice—Frederick J. Converse

The papers along with discussion have been issued as *ASTM Special Technical Publication No. 131*, entitled "Symposium on Direct Shear Testing of Soils."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON EXCHANGE PHENOMENA IN SOILS

This Symposium took place on June 27, 1952, in New York, N. Y., at the Thirty-fourth Session of the Fifty-fifth Annual Meeting of the Society, and was sponsored by Committee D-18 on Soils for Engineering Purposes. Various applications and experiences in connection with ion exchange reactions are discussed in the five papers.

The following papers were presented:

Introduction—Richard C. Mielenz
Ion Exchange in Relation to Some Properties of Soil-Water Systems—Ralph E. Grim
Cation Exchange Capacity in Loess and Its Relation to Engineering Properties—Donald T. Davidson and John B. Sheeler
Job Experience with Exchange Phenomena Involving Inorganic and Organic Ions—Hans F. Winterkorn
Surface-Chemical Properties of Clay Minerals and Soils—Hans F. Winterkorn and Gerhard Schmid
Some Effects of Treating Expansive Clays with Calcium Hydroxide—Irving Goldberg and Alexander Klein
Summary—Edward F. Preece

The papers together with discussions are issued by *ASTM as Special Technical Publication No. 142*, entitled "Symposium on Exchange Phenomena in Soils."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON CONTINUOUS ANALYSIS OF INDUSTRIAL WATER AND INDUSTRIAL WASTE WATER

This Symposium was arranged by Committee D-19 on Industrial Water and took place at the Seventh and Eleventh Sessions of the Fifty-fifth Annual Meeting of the Society in New York, N. Y., June 24, 1952. The papers showed how automatic equipment may be used to provide better methods for solving analytical problems connected with industrial water.

The following papers were presented:

Introduction—B. W. Dickerson
Automatic Sampling of Industrial Water and Industrial Waste Water—M. F. Madarasz
Some Practical Aspects of the Measurement of pH, Electrical Conductivity, and Oxidation-Reduction Potential of Industrial Water—Robert Rosenthal
Continuous Recording of Chlorine Residuals and Determination of Chlorine Demand—A. E. Griffin
Measurement of Color, Turbidity, Hardness, and Silica in Industrial Waters—F. C. Staats
Continuous Measurement of Dissolved Gases in Water—J. K. Rummel

These papers and discussions have been issued as *ASTM Special Technical Publication No. 130*, entitled "Symposium on Continuous Analysis of Industrial Water and Industrial Waste Water."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON NON-DESTRUCTIVE TESTING

A session on non-destructive testing was sponsored by Committee E-7 on Non-destructive Testing at the Fifty-fifth Annual Meeting of the Society in New York, N. Y., on June 26, 1952. Foreign authors presented a number of papers on types of non-destructive tests as conducted in their own countries.

The following papers were presented:

Field Radiography in Denmark; New Methods and Equipment—Hans Vinter
Development of Standard Comparison Radiographs of Steel Welds—A. Gobus and N. A. Kahn
Fluoroscopy and Radiography with Iridium 192—C. Garrett, G. Rice, and A. H. Morrison
Weld Radiography: A Tentative Method for the Quantitative Evaluation of Defects—O. Masi
Critical Study of Techniques for the Testing of Materials by Ultrasonic Methods—P. Bastien
Comparison of Non-destructive Tests on a Damaged Stern-Post—A. de Sterke and H. den Hartog
Progress in the Field of Non-destructive Testing Through the Use of Ultrasonics—W. C. Hitt
The Practical Application of Ultrasonic Non-destructive Testing—W. E. Felix
New Magnetic Non-destructive Tests—E. Forster

The papers with their discussions are issued as *ASTM Special Technical Publication No. 145*, entitled "Symposium on Non-Destructive Testing."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON STATISTICAL METHODS FOR THE DETERGENT LABORATORIES

The papers in this Symposium are concerned with the statistical analysis of tests used for detergent evaluation. The significance of various methods and their correlation with practice is emphasized. The papers were presented at a meeting of ASTM Committee D-12 on Soaps and Other Detergents held on March 18, 1952, in New York, N. Y.

The following papers were included:

- Introduction—Jay C. Harris
- Graphical Methods of Statistical Analysis and Tests for Significance—P. L. Schmidt
- The Design of Laboratory Control of Laundry Washrooms Based on an Analysis of Variance—George S. Freeman and Morris I. Cohn
- The Importance of Correlations in Detergency Testing—Joseph M. Lambert and Edward J. Leshan

The papers have been issued as ASTM Special Technical Publication No. 139, entitled "Symposium on Statistical Methods for the Detergent Laboratories."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON CONDITIONING AND WEATHERING

Committee E-1 on Methods of Testing sponsored a Symposium on Conditioning and Weathering at the Ninth Session of the Society's for Fifty-fifth Annual Meeting held in New York, N. Y., on June 24, 1952. Many materials require temperature and humidity conditioning prior to if not during testing, and this Symposium provided an up-to-date review of the field of conditioning and weathering practices.

The following papers were presented:

Introduction—Robert Burns
Fundamentals of Atmospheric Elements—B. C. Haynes
Air Conditioning in the Manufacture and Testing of Textiles—R. H. Brown
Conditioning and Weathering of Paper—William R. Willets
Conditioning and Weathering of Adhesives and Plastics—Frank W. Reinhart
Weathering of Some Organic Coatings—E. J. Dunn, Jr.
Weathering Tests on Metallic Coatings—William Blum
Laboratory Air Conditioning—A. E. Stacey, Jr.
Development of a Moisture Resistance Test—C. P. Lascaro
Outdoor Exposure Testing on Racks and Test Fences—K. G. Compton
Accelerated Weathering Devices—Roscoe H. Sawyer

These papers and their discussions have been issued by *ASTM as Special Technical Publication No. 133,* entitled "Symposium on Conditioning and Weathering."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON LIGHT MICROSCOPY

At the Sixteenth and Twentieth Sessions of the Fifty-fifth Annual Meeting of the Society, held on June 25, 1952, in New York, N. Y., Committee E-1 on Methods of Testing sponsored a Symposium on Light Microscopy. Papers on the methods of microscopy and apparatus used were followed by others that dealt with specialized applications of the light microscope.

The following papers were included:

Introduction—R. P. Loveland
The Methods of Microscopy—C. W. Mason
Apparatus for Microscopy—H. W. Zieler
Some Applications of Light Microscopy in the Study of Textile Materials—Verne W. Tripp
Polarized Light Microscopy and Supplementry Techniques—W. C. McCrone
Applications of Light Microscopy in Concrete Research—Katharine Mather
The Microscopic Examination of Metallic Specimens—J. R. Vilella
Resinography, the Microscopy of Resin and Their Plastics—T. G. Rochow
Method of Particle—Size Analysis—R. P. Loveland

The papers and their discussions were issued as *ASTM Special Technical Publication No. 143*, entitled "Symposium on Light Microscopy."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON THE USE OF RADIOISOTOPES IN SOIL MECHANICS

This Symposium was presented at a meeting of ASTM Committee D-18 on Soils for Engineering Purposes held in Cleveland, Ohio, on March 5, 1952. The papers deal with the application of certain phases of atomic science to the problem of soil strength analysis.

The following papers were included:

Introduction—Miles D. Catton
Radioisotopes and Nuclear Reactions Applied to Soil Mechanics Problems—Harold E. Hosticka
Use of Radioactive Material to Measure Soil Moisture and Density—Donald J. Belcher, Raymond C. Herner, T. R. Cuykendall, and H. S. Sack
Determining Soil Moisture and Density by Nuclear Radiations—D. A. Lane, B. B. Torchinsky, and J. W. T. Spinks

The papers were issued as ASTM Special Technical Publication No. 134, entitled "Symposium on the Use of Radioisotopes in Soil Mechanics."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON INSULATING OILS

At a meeting of ASTM Committee D-9 on Electrical Insulating Oils held at Niagara Falls, Ontario, Can., November, 1951, two papers on transformer oil were presented. This Symposium is the fourth of a series sponsored by Subcommittee IV on Liquid Insulation of ASTM Committee D-9 to consider the properties of insulating liquids and the significance of various methods of test.

The following papers were included:

Introduction—L. B. Schofield
Evaluation of Mineral Transformer Oil During Service. Part II: Correlation of Oil Characteristics with Continued Transformer Operation—F. M. Clark
Evaluation of Mineral Transformer Oil During Service. Part III: An Examination of Selected Transformers—R. G. Call, F. M. Clark, and T. A. McConnell

These papers and their discussions were issued as ASTM Special Technical Publication No. 135, entitled "Symposium on Insulating Oils."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON CHEMICAL ANALYSIS OF INORGANIC SOLIDS BY MEANS OF THE MASS SPECTROMETER

This Symposium, sponsored by Committee E-2 on Emission Spectroscopy, was presented at a meeting of Committee E-2 held on June 20, 1951, in Atlantic City, N. J., during the Fifty-fourth Annual Meeting of the American Society for Testing Materials. The papers deal with a field of spectroscopy that may provide a means of parallel analysis of materials now being analyzed by optical spectroscopy.

The following papers were presented:

The Mass Spectrometer as a Tool for the Determination of Trace Element Impurities in Solid Samples—Mark G. Inghram

Mass Spectrometric Analysis of Solids with the High-Frequency Sparks—J. A. Hipple and J. G. Gorman

Mass Spectrometric Analysis of Copper for Cuprous-Oxide Rectifiers—W. M. Hickam

These papers have been issued as ASTM Special Technical Publication No. 149, entitled "Symposium on Chemical Analysis of Inorganic Solids by Means of the Mass Spectrometer."

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LIST OF SPECIAL TECHNICAL PUBLICATIONS

The publications listed below have been printed during the year 1952 and issued as separate publications not included in either Proceedings or ASTM BULLETIN. For a list of earlier Special Technical Publications, see the original listing in Proceedings, Volume 48, page 1352, and the supplementary listings in Volume 49, page 1240, Volume 50, page 1490, and Volume 52, page 1322. A complete list of Special Technical Publications covering all publications, up to and including 1950, is included in the 50 Year Index to ASTM Publications.

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128	Symposium on Strength and Ductility of Metals at Elevated Temperatures With Particular Reference to Effects of Notches and Metallurgical Changes (1952).
129	Symposium on Determination of Elastic Constants (1952).
130	Symposium on Continuous Analysis of Industrial Water and Industrial Waste Water (1952).
131	Symposium on Direct Shear Testing of Soils (1952).
132	Symposium on Plastics Testing—Present and Future (1952).
133	Symposium on Conditioning and Weathering (1952).
134	Symposium on Use of Radioisotopes in Soil Mechanics (1952).
135	Symposium on Insulating Oil (1952).
136	Symposium on Recent Developments in the Evaluation of Natural Rubber (1952).
137	Fatigue, with Emphasis on Statistical Approach II (1952).
138	Symposium on Testing Adhesives for Durability and Permanence (1952).
139	Statistical Method for the Detergent Laboratories (1952).
140	Symposium on Metal Powders (1952).
141	Symposium on Tin (1952).
142	Symposium on Exchange Phenomena in Soils (1952).
143	Symposium on Light Microscopy (1952).
144	Symposium on Fretting Corrosion (1952).
145	Symposium on Non-Destructive Testing (1952).
146	Bibliography of Publications on Soil Dynamics (1952).
147	Symposium on Paint (1952).
148	Manual on Industrial Water (1952).
149	Symposium on Chemical Analysis of Inorganic Solids by Means of Mass Spectrometer (1951).